COMPUTER-AIDED ANALYSIS OF BALANCING OF MULTI-CYLINDER RADIAL AND V- ENGINES

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By

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Certificate of Approval

This is to certify that the thesis entitled COMPUTER AIDED ANALYSIS OF BALANCING OF MULTI CYLINDER RADIAL AND VEE ENGINES submitted by Sri Chinmoy krushna Mohapatra has been carried out under my supervision in partial fulfilment of the requirements for the Degree of Bachelor of Technology (B. Tech.) in Mechanical Engineering at National Institute of Technology, NIT Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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CONTENTS

ABSTRACT

The reciprocating engines are the prime source of power generation in various mechanical applications ranging from power generation to automobiles. Noise, vibrations and harshness are caused in this engine due to unbalanced inertia forces and moments which further cause complications in their operation. To minimise the unbalance, analysis for the unbalanced forces and moments for different configuration of cylinders and firing order of multi-cylinder radial and V engines are done. The C programs have been developed for this analysis to minimise the time and calculations. The radial, V engines and combined radial and inline configured engines are compared on the basis of resultant unbalanced forces and moments.

CHAPTER # 1

INTRODUCTION

A reciprocating engine may be a heat engine that uses one or over one reciprocating pistons to convert pressure into a rotating motion. These engines are used extensively in cars, power generators and aircrafts. Multi-cylinder engines use over one cylinder that is employed extensively today. These engines will be inline, v-type, radial or combination of any 2 kinds of engines.

Inline engines are typically employed in four- and six-cylinder configurations, with all cylinders aligned in one row, with no offset. they're getting used in vehicles, locomotives and aircraft, though the word in-line incorporates a broader which means in case of aircraft engines .It is significantly easier to make an inline engine than identical horizontally opposed or V engine, as a result of each the cylinder bank and crankshaft are often milled from one metal casting, and fewer cylinder heads and camshafts are needed. In-line engines have bigger benefits of smaller in overall physical dimensions over the styles just like the radial, and might be mounted in any direction. Straight configurations are easier than their counterparts of V-shaped. Inline engines have a support bearing between every piston as compared to "flat and V" engines that have support bearings between each 2 pistons.

A V engine may be told as a common configuration in case of an enclosed combustion engine. The pistons and cylinders are aligned, in 2 separate planes or 'banks' separated by an angle known as v angle so they seem to be in an exceedingly "V" when viewed along the axis of the crankshaft. The V configuration helps in reducing the general engine length, height and weight compared to a similar inline configuration. Numerous cylinder bank angles of V i.e. V angle are employed in totally different engines; that depends on the amount of cylinders. the widely and widely used V angles are 600 , 450,300,900. These varieties of engines are usually employed in cars and aircrafts. Engines of V configurations are well-balanced and smooth. Counterweights on the crankshaft are mainly used for the balancing of the V10 and cross plane V8 engine. V12 engines always have even firing and exceptional balance irrespective of V angle.

The radial engine could be told as a reciprocating kind IC engine during which the cylinders purpose outward from a central crankshaft rather like the spokes on a wheel. This configuration was widely employed in giant aircraft engines before the begin of turbine engines. in an exceedingly radial engine, master-and-articulating-rod assembly is employed to attach the pistons to the crankshaft. Four-stroke radial engines continuously have an odd variety of cylinders per row to urge an identical every-other-piston firing order ensuing swish operation, that is achieved by the engine taking 2 revolutions of the crankshaft to complete the four strokes. As a result there's continuously a two-piston gap between the piston on its power stroke and therefore the next piston on its compression stroke. On the opposite hand in case of a good variety of cylinders a three-piston gap between firing pistons on the primary crank shaft revolution , and solely a one-piston gap on the second crank shaft revolution is observed, that ends up in an uneven firing order at intervals the engine. These engines are well balanced. there's no unbalanced torque within the plane of radial engines.

Nowadays multi row radial engines have replaced the single row radial engine in case of large aero engine due to certain advantages. In multi row radial engines multiple no. Of radial engines with some offset distance are connected by a common shaft . Here we can get even number of cylinders by the combination of radial engines with odd number of cylinders arranged in even number of rows. These engines are considered when high power is required. These engines are also well balanced compared to their counterpart single row radial engines. The bigger advantage of this type of engines over radial engines is: these types of engines can be easily cooled as compactness is less.

CHAPTER # 2

LITERATURE REVIEW

Vigen H. Arakelian and M. R. Smith [1] have worked together for finding the solutions of the problem of the shaking moment and shaking force balancing of planar mechanisms by using totally different ways based on the generation of the movements of counterweights. They also examined some special cases like balancing ways based on the copying properties of pantograph systems that carry the counterweights.

Esat and H. Bahai [2] have worked together on complete force balancing of planar linkage by the help of criterion of Lowen and Tepper, then it can be completely force and moment balanced using geared counter-inertias. Lowen and Tepper have shown that complete force balancing of planar linkage is possible using straightforward counterweights such that from every purpose on the linkage there exists a contour to the ground in type of revolute joints only.

V. Arakelian and N. Makhsudyan [3] proposed the generalised Lanchester Balancer that helps in shaking force balancing of crank slider mechanisms of enormous eccentricity. within the case of classical lanchester device the balancing is dole out by counter rotating weights. however during this case the concentration of weights is determined by taking the ecenticricty of slider guider in to consideration.

Floyd A. Wyczalek [4] has worked on generalised balance ofreciprocating engines e.g. inline , vee and opposite piston engine. He derived four mathematical expressions for generalisation of the balance characteristics of automotive engines that described the unbalanced forces and moments of a reciprocating engine as functions of various parameters like variety of cylinders , vee angle and cylinder bank offset. These unique relations work for any cylinder vee- angle and for any configuration having no. Of cylinders 24 .

W Harry close, Wieslaw Szydlowski and Christopher Downton [5] have worked on balancing of all forces and moments created thanks to pistons, connecting rods and crankshaft of the Collins family of 12, 8, six and four cylinder engines. By the help of the Scotch Yoke mechanism there are no secondary forces, or higher order forces, and so the counter-balancing required can be calculated precisely.

H. D. Desai [6] has worked on pc aided analysis i.e. kinematic and dynamic analysis of a horizontal slider crank mechanism employed in a single-cylinder four stroke IC engine. His investigation provides the whole kinematic theory of the driven links and also the bearing hundreds for the complete operating cycle of the engine mechanism.

A coppens[7] worked on modification of the formula for computing counter weights of single-row and double row radial engines. He suggested a complementary term should be added to the regular formula for computing the counter weights of single row and double row engines.

K wan- Hee suh, Yoon –Ki Lee, Hi-Seak Yoon[8] worked on the balancing of a reciprocating internal combustion engine having 3 cylinders with crankshafts separated by a part difference of 1200. The result shows the full add of unbalanced inertia force is zero. so he advised a balanced shaft should be present to counter balance the unbalanced torque

CHAPTER # 3

BALANCING

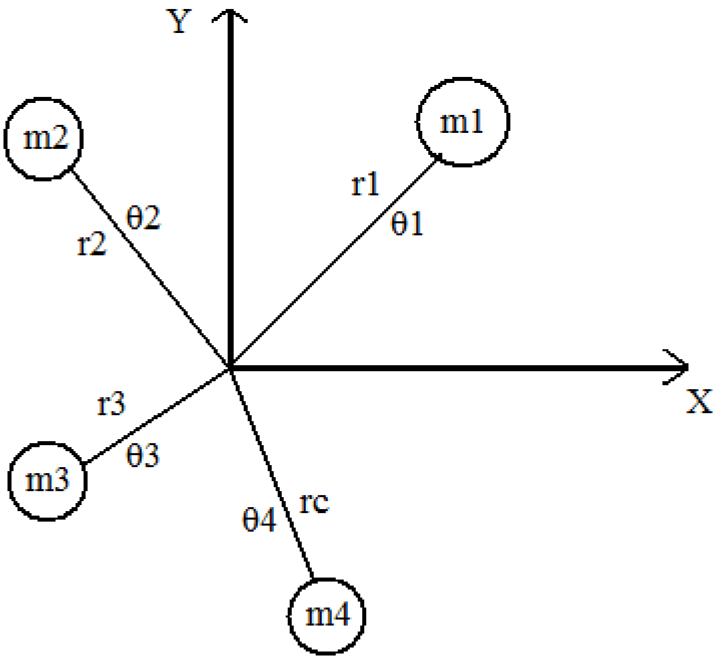
The inertia forces related to moving mass present in rotary or reciprocating machinery manufacture unbalance of force. Balancing is that the method of planning or modifying machinery so the unbalance is reduced to a permissible level and if doable is eliminated entirely. The time varying unbalance forces exerted on the frame by the moving machine provides vibrating motion to border and leads to noise production thus so as to avoid the catastrophic failure of machine caused owing to noise, vibration and harshness.

The foremost common approach for balancing is by redistributing the lots which can be accomplished by adding or removing some quantity of mass from numerous machine members. There are 2 basic styles of unbalance, reciprocating unbalance and rotating unbalance, which can occur individually or together.

BALANCING OF ROTATING MASSES

1. STATIC BALANCING

A system of rotating masses is claimed to be in static balance when the combined centre of mass of the system lies on the axis of rotation.



The above picture shows a rigid rotor rotating at a relentless angular velocity ω rad/s whereas four masses are placed in same transverse plane however at totally different angular and radial positions.

For static balance,

$\Sigma\ mr\cos\theta = m1r1\cos\theta1 + m2r2\cos\theta2 + m3r3\cos\theta3 + m4r4\cos\theta4 = 0$

and $\Sigma\ mr\sin\theta = m1r1\sin\theta1 + m2r2\sin\theta2 + m3r3\sin\theta3 + m4r4\sin\theta4 = 0$

DYNAMIC BALANCING

When several masses rotate in several planes, the unbalanced centrifugal forces form an unbalanced couple .A system of rotating masses is claimed to be in dynamic balance when there doesn't exist any resultant centrifugal force in addition a resultant couple.

BALANCING OF RECIPROCATING MASSES

Acceleration of the reciprocating mass of a slider-crank mechanism is given by the equation
Therefore, the forces required to accelerate mass m is,

$F= m\, r\omega^2\, [\cos\theta + (\cos 2\theta)/n]$

$= m\, r\omega^2 \cos\theta + m\, r\omega^2\, (\cos 2\theta)/n$

primary force **secondary force**

Maximum value of primary force = $mr\omega^2$

Maximum value of secondary force = $mr\omega^2 /n$

Where $n=L/R$ is much greater than unity; hence the secondary force is smaller compared to primary force and can be safely ignored for slow speed engines.

PRIMARY AND SECONDARY BALANCE

Primary balance is that the balance achieved by compensating for the eccentricities of the rotating masses, together with the connecting rods. Primary balance is controlled by addition or removal of mass to or from the crankshaft, at every end, at the required radius and angle, that changes both owing to style and manufacturing tolerances. Theoretically any typical engine will be balanced utterly for primary balance.

Secondary balance is attained by compensating partially or fully for:

- Kinetic energy of the pistons.
- Non-sinusoidal motion of the pistons.
- Motion of the connecting rods.
- Sideways motion of balance shaft weights.

The second of these is the important thought for secondary balance. There are two important management mechanisms for secondary balance—matching the phasing of pistons along the crank, as a result their second order contributions get cancelled, and the use of balance shafts that run at twice engine speed, and thus will provide a force for balancing.

No commonly used engine configuration is perfectly balanced in respect of secondary excitation. however by practising sure definitions for secondary balance, particular configurations will be correctly claimed to be moderately balanced no matter these restricted senses.

CHAPTER # 4

THEORETICAL ANALYSIS OF BALANCING OF MULTI-CYLINDER V-ENGINES

A V engine is a common configuration for an IC engine. The axial planes where the two sets of pistons reciprocate intersect at the crankshaft axis and form a V of angle β. In case of automotive installations, V-6 and V-8 engines are used generally in which β is either 60˚ or 90˚. The 90˚ V-angle is most preferred and generally used. The V configuration generally helps in reducing the overall engine length, height and weight compared to a counterpart inline configuration. The most common configuration used is V2, V4, V6, V8, V10 and V12. The forces and couples for different cylinder numbers and firing order are analyzed below theoretically.

V Engine with 2n cylinders

No. Of cranks: n

Angle made by the first crank with the axis = θ

V angle = β= 2α

Angular Positions of cranks on the crankshaft

$\phi 1 = 0°$

$\phi 2 = \phi 1$

$\phi 3 = \phi 2$

: : : : : :

$\Phi n\text{-}1 = \phi n\text{-}2$

$\Phi n = \phi n\text{-}1$

SHAKING FORCES

$\Sigma (\cos\phi_i) = (\cos\phi_1) + \cos\phi_2 + \cos\phi_3 + \ldots\ldots\ldots + \cos\phi_{n-1} + \cos\phi_n$

$\Sigma \sin\phi_i = \sin\phi_1 + \sin\phi_2 + \sin\phi_3 + \ldots\ldots\ldots + \sin\phi_{n-1} + \sin\phi_n$

$\Sigma \cos2\phi_i = \cos2\phi_1 + \cos2\phi_2 + \cos2\phi_3 + \ldots\ldots\ldots \cos2\phi_{n-1} + \cos2\phi_n$

$\Sigma \sin2\phi_i = \sin2\phi_1 + \sin2\phi_2 + \sin2\phi_3 + \ldots\ldots\ldots + \sin2\phi_{n-1} + \sin2\phi_n$

Primary force along x- axis $=F_{Px}$

Primary force along y- axis = F_{Py}

Total primary force = F_P

Similarly secondary force along x& y axis are F_{Sx} and F_{SY} respectively

Total secondary force = F_S

$F_{Px} = mr\omega^2 \cos\alpha\ [\{\cos(\theta+\alpha)+ \cos(\theta-\alpha)\}\ \Sigma (\cos\phi_i) – \{\sin(\theta+\alpha)+ \sin(\theta-\alpha)\}\Sigma (\sin\phi_i)]$

$F_{Py} = mr\omega^2 \sin\alpha\ [\{\cos(\theta-\alpha)- \cos(\theta+\alpha)\}\ \Sigma (\cos\phi_i) – \{\sin(\theta-\alpha)- \sin(\theta+\alpha)\}\Sigma (\sin\phi_i)]$

And, $F_P = ((F_{Px})^2+ (F_{PY})^2)^{½}$

$F_{Sx}= mr\omega^2 /n\cos2\alpha\ [\{\cos2(\theta+\alpha)+ \cos2(\theta-\alpha)\}\ \Sigma (\cos2\phi_i) – \{\sin2(\theta+\alpha)+ \sin2(\theta-\alpha)\}\Sigma (\sin2\phi_i)]$

$F_{Sy}= mr\omega^2 /n\sin2\alpha\ [\{\cos2(\theta-\alpha)- \cos2(\theta+\alpha)\}\ \Sigma (\cos2\phi_i) – \{\sin2(\theta-\alpha)- \sin2(\theta+\alpha)\}\Sigma (\sin2\phi_i)]$

$F_S = ((F_{Sx})^2+ (F_{SY})^2)^{½}$

SHAKING COUPLES/MOMENTS

$\Sigma (a_i\cos\phi_i) = a_1*(\cos\phi_1) + a_2*(\cos\phi_2) + a_3*(\cos\phi_3) + \ldots\ldots\ldots + a_{n-1}*(\cos\phi n\text{-}1) + a_n*(\cos\phi n)$

$\Sigma (a_i\sin\phi_i) = a_1*(\sin\phi_1) + a_2*(\sin\phi_2) + a_3*(\sin\phi_3) + \ldots\ldots\ldots + a_{n-1}*(\sin\phi n\text{-}1) + a_n*(\sin\phi n)$

$\Sigma (a_i\cos2\phi_i) = a_1*(\cos2\phi_1) + a_2*(\cos2\phi_2) + a_3*(\cos2\phi_3) + \ldots\ldots\ldots + a_{n-1}*(\cos2\phi n\text{-}1) + a_n*(\cos2\phi n)$

$\Sigma (a_i \sin 2\phi_i) = a_1*(\sin 2\phi_1) + a_2*(\sin 2\phi_2) + a_3*(\sin 2\phi_3) + \ldots\ldots\ldots + a_{n-1}*(\sin 2\phi n\text{-}1) + a_n*(\sin 2\phi n)$

Where $a_1 = (n-1)/2$, $a_2 = a_1 - 1, a_3 = a_2 - 1, \ldots\ldots\ldots a_n = a_{n-1} - 1$

If "l" represents the distance between any two consecutive cylinders then,

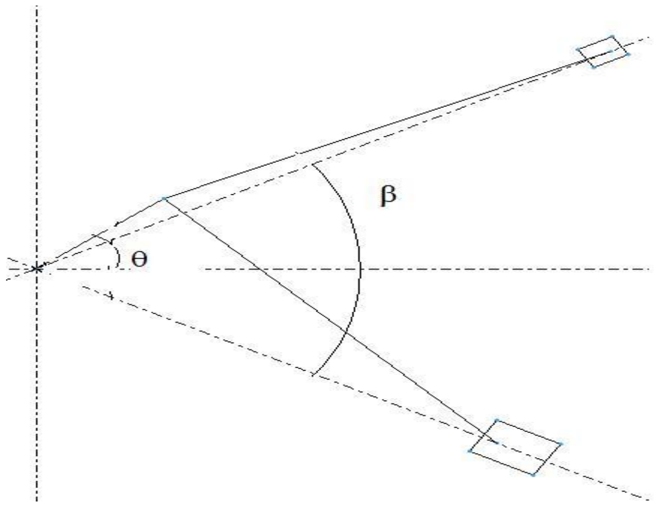
Primary couple along the central axis (C_P)

$= mr\omega^2 l*\cos\alpha[\{\cos(\theta+\alpha)+\cos(\theta-\alpha)\} \Sigma (a_i\cos\phi_i) - \{\sin(\theta+\alpha)+\sin(\theta-\alpha)\} \Sigma (a_i\sin\phi_i)]$

Secondary couple along the central axis (C_S)=

$mr\omega^2 l/n*\cos\alpha[\{\cos 2(\theta+\alpha)+\cos 2(\theta-\alpha)\}\Sigma(a_i\cos 2\phi_i) - \{\sin 2(\theta+\alpha)+\sin 2(\theta-\alpha)\}\Sigma(a_i\sin 2\phi_i)]$

V-2 ENGINE ANALYSIS



$\phi_1 = 0°$

hence $\Sigma(\cos\phi_i) = 1 = \Sigma \cos 2\phi_i$, $\Sigma \sin 2\phi_i = 0 = \Sigma \sin\phi_i$

$F_{Px} = mr\omega^2 \cos\alpha [\{\cos(\theta+\alpha)+ \cos(\theta-\alpha)\}]$

$F_{Py} = mr\omega^2 \sin\alpha [\{\cos(\theta-\alpha)- \cos(\theta+\alpha)\}]$

, $F_P = ((F_{Px})^2+ (F_{PY})^2)^{½}$

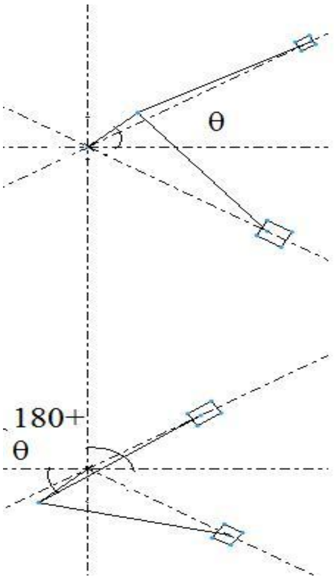
$F_{Sx} = mr\omega^2 /n\cos 2\alpha [\{\cos 2(\theta+\alpha)+ \cos 2(\theta-\alpha)\}]$

$F_{Sy} = mr\omega^2 /n\sin 2\alpha [\{\cos 2(\theta-\alpha)- \cos 2(\theta+\alpha)\}]$

$F_S = ((F_{Sx})^2+ (F_{SY})^2)^{½}$

$C_P = C_S = 0$

V-4 ENGINE ANALYSIS



$\phi_1 = 0°$
$\phi_2 = 180^0$

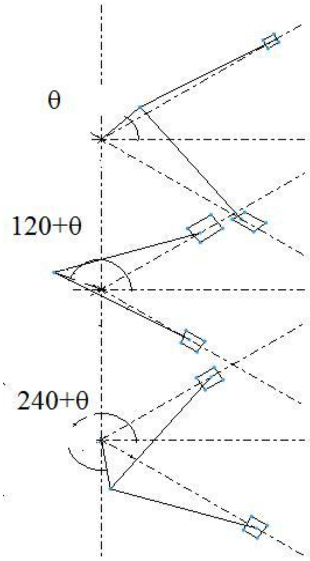
SHAKING FORCES

$\Sigma\cos\phi_i = \cos 0° + \cos 180° = 0$
$\Sigma\sin\phi_i = \sin 0° + \sin 180° = 0$
$\Sigma\cos 2\phi_i = \cos 0° + \cos 360° = 2$
$\Sigma\sin 2\phi_i = \sin 0° + \sin 360° = 0$
$F_{Px} = 0 = F_{Py} = F_P$
$F_{Sx} = mr\omega^2 / n\cos 2\alpha\ [2\{\cos 2(\theta+\alpha) + \cos 2(\theta-\alpha)\}\ ]$
$F_{Sy} = mr\omega^2 / n\sin 2\alpha\ [2\{\cos 2(\theta-\alpha) - \cos 2(\theta+\alpha)\}\ ]$
$F_S = ((F_{Sx})^2 + (F_{SY})^2)^{½}$

SHAKING COUPLES/MOMENTS

$a_1 = ½$, $a_2 = -½$
$\Sigma(a_i\cos\phi_i) = 1$
$\Sigma(a_i\sin\phi_i) = 0$
$\Sigma(a_i\cos 2\phi_i) = 0$
$\Sigma(a_i\sin 2\phi_i) = 0$
Primary couple along the central axis (C_P)
$= mr\omega^2 l * \cos\alpha[\{\cos(\theta+\alpha) + \cos(\theta-\alpha)\}\ ]$
Secondary couple along the central axis (C_S)= 0

V-6 ENGINE ANALYSIS



$\phi_1 = 0°$
$\phi_2 = 120^0$
$\phi_3 = 240^0$

SHAKING FORCES

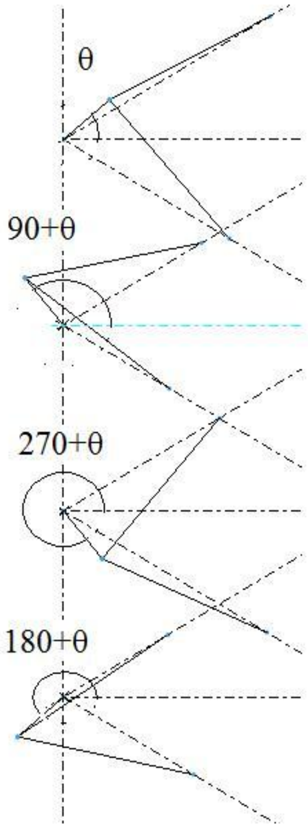
$\Sigma \cos\phi_i = \cos0° + \cos240° + \cos120° = 0$
$\Sigma \sin\phi_i = \sin0° + \sin240° + \sin120° = 0$
$\Sigma \cos2\phi_i = \cos0° + \cos480° + \cos240° = 0$
$\Sigma \sin2\phi_i = \sin0° + \sin480° + \sin240° = 0$
Hence $F_{Px} = F_{Py} = F_{Sx} = F_{Sy} = 0$

SHAKING COUPLES

$\Sigma (a_i\cos\phi_i) = 1.5$
$\Sigma (a_i\sin\phi_i) = 0.866$
$\Sigma (a_i\cos2\phi_i) = 1.5$
$\Sigma (a_i\sin2\phi_i) = -0.866$

Primary couple along the central axis (C_P)
$=mr\omega^2 l*\cos\alpha[1.5\{\cos(\theta+\alpha)+\cos(\theta-\alpha)\} - 0.866\{\sin(\theta+\alpha)+\sin(\theta-\alpha)\}]$
Secondary couple along the central axis (C_S)=
$mr\omega^2 l/n*\cos\alpha[1.5\{\cos2(\theta+\alpha)+\cos2(\theta-\alpha)\}+0.866\{\sin2(\theta+\alpha)+\sin2(\theta-\alpha)\}]$

V-8 ENGINE ANALYSIS



$\phi_1 = 0°$
$\phi_2 = 90^0$
$\phi_3 = 270^0$
$\phi_4 = 180^0$

SHAKING FORCES

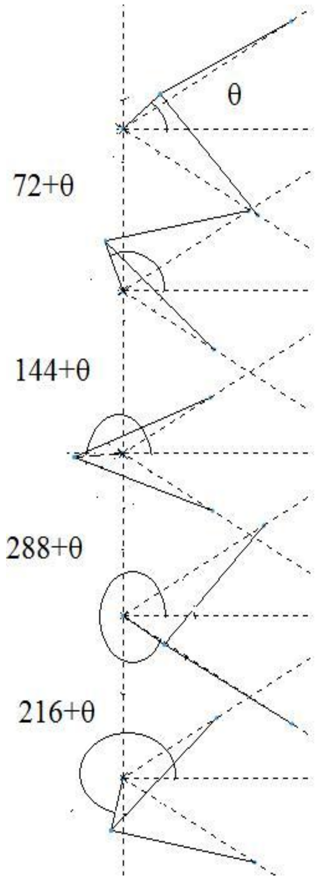
$\Sigma \cos\phi_i = \cos 0° + \cos 90° + \cos 270° + \cos 180^0 = 0$
$\Sigma \sin\phi_i = \sin 0° + \sin 90° + \sin 270° + \sin 180^0 = 0$
$\Sigma \cos 2\phi_i = \cos 0° + \cos 180° + \cos 540° + \cos 360^0 = 0$
$\Sigma \sin 2\phi_i = \sin 0° + \sin 180° + \sin 540° + \sin 360^0 = 0$
Hence $F_{Px} = F_{Py} = F_{Sx} = F_{Sy} = 0$

SHAKING COUPLES

$\Sigma (a_i\cos\phi_i) = 3$
$\Sigma (a_i\sin\phi_i) = 1$
$\Sigma (a_i\cos 2\phi_i) = 0$
$\Sigma (a_i\sin 2\phi_i) = -0$

Primary couple along the central axis (C_P)
$=mr\omega^2 l*\cos\alpha[3\{\cos(\theta+\alpha)+\cos(\theta-\alpha)\} - \{\sin(\theta+\alpha)+\sin(\theta-\alpha)\}]$
Secondary couple along the central axis (C_S)= 0

V-10 ENGINE ANALYSIS



$\phi_1 = 0°$
$\phi_2 = 72^0$
$\phi_3 = 144^0$
$\phi_4 = 288^0$
$\phi_5 = 216^0$

SHAKING FORCES

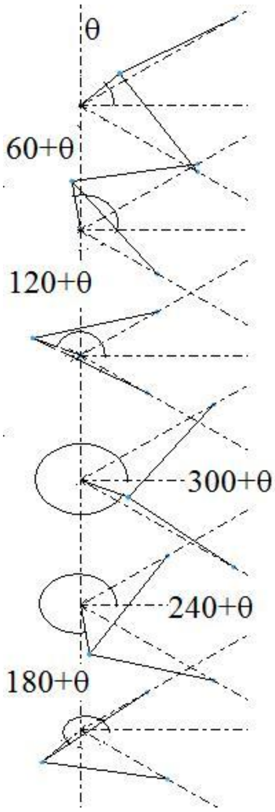
$\Sigma \cos\phi_i = \cos 0° + \cos 216° + \cos 144° + \cos 72° + \cos 288° = 0$
$\Sigma \sin\phi_i = \sin 0° + \sin 216° + \sin 144° + \sin 72° + \sin 288° = 0$
$\Sigma \cos 2\phi_i = \cos 0° + \cos 432° + \cos 288° + \cos 144° + \cos 576° = 0$
$\Sigma \sin 2\phi_i = \sin 0° + \sin 432° + \sin 288° + \sin 144° + \sin 576° = 0$
Hence $F_{Px} = F_{Py} = F_{Sx} = F_{Sy} = 0$

SHAKING COUPLES

$\Sigma (a_i \cos\phi_i) = 3$
$\Sigma (a_i \sin\phi_i) = 1$
$\Sigma (a_i \cos 2\phi_i) = 0$
$\Sigma (a_i \sin 2\phi_i) = -0$

Primary couple along the central axis (C_P)
$= mr\omega^2 l * \cos\alpha[3\{\cos(\theta+\alpha)+\cos(\theta-\alpha)\} - \{\sin(\theta+\alpha)+\sin(\theta-\alpha)\}]$
Secondary couple along the central axis (C_S)= 0

V-12 ENGINE ANALYSIS



$\phi_1 = 0°$
$\phi_2 = 60^0$
$\phi_3 = 120^0$
$\phi_4 = 300^0$
$\phi_5 = 240^0$
$\phi_6 = 180^0$

SHAKING FORCES

$\Sigma \cos\phi_i = \cos0° + \cos60° + \cos120° + \cos300° + \cos240° + \cos180^0 = 0$
$\Sigma \sin\phi_i = \sin0° + \sin60° + \sin120° + \sin300° + \sin240° + \sin180^0 = 0$
$\Sigma \cos2\phi_i = \cos0° + \cos120° + \cos240° + \cos600° + \cos480° + \cos360^0 = 0$
$\Sigma \sin2\phi_i = \sin0° + \sin120° + \sin240° + \sin600° + \sin480° + \sin360^0 = 0$
Hence $F_{Px} = F_{Py} = F_{Sx} = F_{Sy} = 0$

SHAKING COUPLES

$\Sigma (a_i\cos\phi_i) = 6$
$\Sigma (a_i\sin\phi_i) = 3.464$
$\Sigma (a_i\cos2\phi_i) = 0$
$\Sigma (a_i\sin2\phi_i) = -0$

Primary couple along the central axis (C_P)
$=mr\omega^2 l*\cos\alpha[6\{\cos(\theta+\alpha)+\cos(\theta-\alpha)\} - 3.464\{\sin(\theta+\alpha)+\sin(\theta-\alpha)\}]$
Secondary couple along the central axis (C_S)= 0

The previous theoretical analysis can also be done for varied engines with increasing range of cylinders like V-14, V-16 and thus on. but calculations will be much more tedious, thus we are going to choose computer-aided analysis of balancing of multi-cylinder V engines. A program has been developed in C language for the specified analysis. The program can evaluate all forces and couples working on the engine for various range of cylinders and different firing orders.

C PROGRAM FOR DYNAMIC ANALYSIS OF MULTI-CYLINDER V-ENGINES

```
#include <stdio.h>
#include <math.h>
#include <conio.h>
const double Pi=3.14159265;
int main()
{
   int k;
   float
i,j,m,ls,R,L,N,b,o,l,n,w,a,O[10],D[10],A[10],AOC,AOCC,AOS,AOSS,TC,TS,TTC,TTS,x,y,fpx,fpy,f
sx,fsy,fp,fs,TUF,cp,cs;
   printf("\nEnter Total no of cylinders\t:");
   scanf("%f",&j);
   printf("\nEnter mass of each cylinder\t:");
   scanf("%f",&m);
   printf("\nEnter length of each stroke\t:");
   scanf("%f",&ls);
   printf("\nEnter length of connecting rod\t:");
   scanf("%f",&L);
   printf("\nEnter RPM of Engine\t:");
   scanf("%f",&N);
   printf("\nEnter V Angle\t:");
   scanf("%f",&b);
   printf("\nEnter Angle between 1st cyl and V-axis\t:");
   scanf("%f",&o);
   printf("\nEnter Distance betwwen two consecutiv cyl bank\t:");
   scanf("%f",&l);
   i=j/2;
   R=ls/2;

   n=L/R;
   b=b*(Pi/180);
   a=b/2;
   o=o*(Pi/180);

   x=o+a;
   y=o-a;
   O[0]=0;
   D[0]=0;
   A[0]=(i-1)/2;
   AOC=A[0]*cos(O[0]);
```

```
    AOS=A[0]*sin(O[0]);
    AOCC=A[0]*cos(2*O[0]);
    AOSS=A[0]*sin(2*O[0]);
    w=(2*Pi*N)/60;
    TC=cos(O[0]);
    TS=sin(O[0]);
    TTC=cos(2*O[0]);
    TTS=sin(2*O[0]);
    for(k=1;k<i;k++)
    {
            printf("\nEnter Angle Between Crank1 and Crank%d\t:",k+1);
            scanf("%f",&D[k]);
            O[k]=D[k]*(Pi/180);
            TC=TC+cos(O[k]);
            TTC=TTC+cos(2*O[k]);
            TS=TS+sin(O[k]);
            TTS=TTS+sin(2*O[k]);
            A[k]=A[k-1]-1;
            AOC=AOC+(A[k]*cos(O[k]));
            AOS=AOS+(A[k]*sin(O[k]));
            AOCC=AOCC+(A[k]*cos(2*O[k]));
            AOSS=AOSS+(A[k]*sin(2*O[k]));
    }
    fpx=(m*R*w*w*cos(a))*((cos(x)*TC)+(cos(y)*TC)-(sin(x)*TS)-(sin(y)*TS));
    fpy=(m*R*w*w*sin(a))*(((cos(x)*TC)*(-1))+(cos(y)*TC)+(sin(x)*TS)-(sin(y)*TS));
    fsx=((m*R*w*w*cos(a))/n)*((cos(2*x)*TTC)+(cos(2*y)*TTC)-(sin(2*x)*TTS)-(sin(2*y)*TTS));
    fsy=((m*R*w*w*sin(a))/n)*(((-1)*cos(2*x)*TTC)+(cos(2*y)*TTC)+(sin(2*x)*TTS)-
(sin(2*y)*TTS));
    fp=sqrt((fpx*fpx)+(fpy*fpy));
    fs=sqrt((fsx*fsx)+(fsy*fsy));
    TUF=sqrt(((fpx+fsx)*(fpx+fsx))+((fpy+fsy)*(fpy+fsy)));
    cp=((m*R*w*w*l*cos(a)))*(((cos(x)+cos(y))*AOC)-((sin(x)+sin(y))*AOS));
    cs=((m*R*w*w*l*cos(a))/n)*(((cos(2*x)+cos(2*y))*AOCC)-((sin(2*x)+sin(2*y))*AOSS));
    printf("\nTC= %f\t",TC);
    printf("\nTS= %f\t",TS);
    printf("\nTTC= %f\t",TTC);
    printf("\nTTS= %f\t",TTS);
    printf("\nAOC= %f\t",AOC);
    printf("\nAOCC= %f\t",AOCC);
    printf("\nAOS= %f\t",AOS);
    printf("\nAOSS= %f\t",AOSS);
    printf("\nfpx= %f\t",fpx);
    printf("\nfpy= %f\t",fpy);
    printf("\nfsx= %f\t",fsx);
    printf("\nfsy= %f\t",fsy);
    printf("\nfp= %f\t",fp);
    printf("\nfs= %f\t",fs);
    printf("\nTUF= %f\t",TUF);
```

```
    printf("\ncp= %f\t",cp);
    printf("\ncs= %f\t",cs);
getch();
return 0;
}
```

CHAPTER # 5

THEORETICAL ANALYSIS OF BALANCING OF MULTI-CYLINDER RADIAL ENGINES

The radial engine is a reciprocating type IC engine in which the cylinders point outward from a central crankshaft just like the spokes on a wheel. This configuration was most commonly used in large aircraft engines before the commence of turbine engines. Four-stroke radial engines always have an odd number of cylinders per row to get a consistent every-other-piston firing order resulting smooth operation, which is achieved by the engine taking two revolutions of the crankshaft to complete the four strokes. As a result there is always a two-piston gap between the piston on its power stroke and the next piston on its compression stroke. On the other hand in case of an even number of cylinders a three-piston gap between firing pistons on the first crank shaft revolution , and only a one-piston gap on the second crank shaft revolution is observed, which leads to an uneven firing order within the engine. The most commonly used configurations are R-3, R-5, R-7, R-9 and R-11.These engines are well balanced. There is no unbalanced torque in the plane of radial engines. These types of engines are balanced by using direct and reverse crank mechanism which is shown below.

Radial engines with n no. Of cylinders

Angle between each stroke axis = $360^0/n$
Hence $\theta_1=0^0$, $\theta_2= 360^0/n$, $\theta_3 = 2* 360^0/n$, $\theta_4 = 3* 360^0/n$,............................ $\theta_n = (n-1)* 360^0/n$

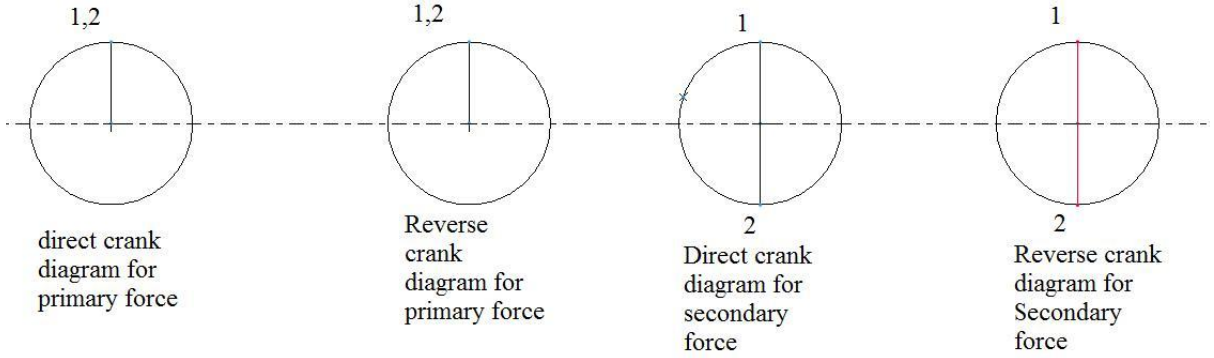
Primary unbalance force

For Direct crank ;
$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} =$...........................$= \Phi_{Pdn} = 0^0$
For reverse crank;
$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =2* 360^0/n$, $\Phi_{Pr3} = 2*(2* 360^0/n)$, ... $\Phi_{Prn} = 2*\{(n-1)*360^0/n\}$
Hence $\Phi_{Pri} = 2*\theta_i$
$\Sigma \cos\Phi_{Pdi} = n$
$\Sigma \cos \Phi_{Pri} = \cos(\Phi_{Pr1}) + \cos(\Phi_{Pr2}) + \cos (\Phi_{Pr3}) +$.....................$\cos(\Phi_{Prn})$
Hence primary force due to direct crank (F_{Pd}) = $(m/2) *r*\omega^2*(\Sigma \cos\Phi_{Pdi})$
Primary force due to reverse crank (F_{Pr}) = $(m/2)*r*\omega^2*(\Sigma \cos\Phi_{Pri})$
Hence primary unbalance force (F_P) = $F_{Pd} +F_{Pr}$

Secondary unbalance force

For direct crank;
$\Phi_{Sdi} = -\theta_i$, , i.e. $\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -360^0/n$, $\Phi_{Sd3} = -2* 360^0/n$, ... $\Phi_{Sdn} = - (n-1)*360^0/n$
For reverse crank;
$\Phi_{Sri} =3*\theta_i$, i.e. $\Phi_{Sr1} = 0^0$, $\Phi_{Sr2} = 3*360^0/n$, $\Phi_{Sr3} = 3*(2*360^0/n)$,.............. $\Phi_{Srn} = 3*\{(n-1)*360^0/n\}$
$\Sigma\cos \Phi_{Sdi} = \cos \Phi_{Sd1} +\cos \Phi_{Sd2}+\cos \Phi_{Sd3}+$....................$\cos \Phi_{Sdn}$
$\Sigma\cos \Phi_{Sri} = \cos \Phi_{Sr1}+ \cos \Phi_{Sr2}+\cos \Phi_{Sr3}+$.......................$\cos \Phi_{Srn}$
Secondary force due to direct crank (F_{Sd}) = $(m/2)*(r/n)*\omega^2* \Sigma\cos \Phi_{Sdi}$
Secondary force due to reverse crank(F_{Sr}) = $(m/2)*(r/n)*\omega^2* \Sigma\cos \Phi_{Sri}$
Total secondary unbalance force(F_S) = $F_{Sd}+F_{Sr}$
Total unbalanced force(F) = F_P+F_S
Total unbalanced couple = 0

R-2 ENGINE ANALYSIS



Angle between each stroke axis = $360^0/2 = 180^0$

Hence $\theta_1=0^0$, $\theta_2= 180^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =360^0$

$\Sigma \cos\Phi_{Pdi} = 2$

$\Sigma \cos \Phi_{Pri} = \cos(0^0) + \cos(360^0)=2$

Hence primary force due to direct crank (F_{Pd}) = $(m/2) *r*\omega^2*2 = m*r* \omega^2$

Primary force due to reverse crank (F_{Pr}) = $(m/2)*r*\omega^2*2 = m*r* \omega^2$

Hence primary unbalance force (F_P) = $2* m*r* \omega^2$

Secondary unbalance force

For direct crank;

$\Phi_{Sdi} = -\theta_{i,}$, i.e. $\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -180^0$

For reverse crank;

$\Phi_{Sr1} = 0^0$, $\Phi_{Sr2} = 540^0$

$\Sigma\cos \Phi_{Sdi} = \cos \Phi_{Sd1} +\cos \Phi_{Sd2}+\cos \Phi_{Sd3}+....................\cos \Phi_{Sdn}$

$\Sigma\cos \Phi_{Sri} = \cos \Phi_{Sr1}+ \cos \Phi_{Sr2}+\cos \Phi_{Sr3}+.......................\cos \Phi_{Srn}$

Secondary force due to direct crank (F_{Sd}) = $(m/2)*(r/n)*\omega^2* \Sigma\cos \Phi_{Sdi}$

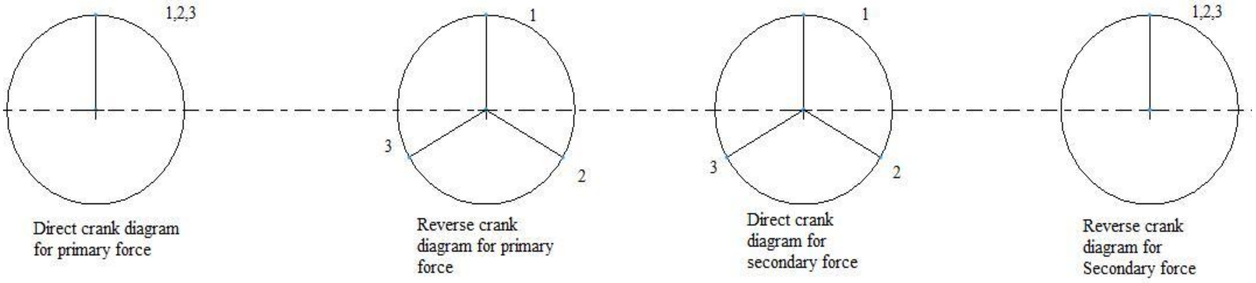
Secondary force due to reverse crank(F_{Sr}) = $(m/2)*(r/n)*\omega^2* \Sigma\cos \Phi_{Sri}$

Total secondary unbalance force(F_S) = $F_{Sd}+F_{Sr}$

Total unbalanced force(F) = F_P+F_S

Total unbalanced couple = 0

R-3 ENGINE ANALYSIS



Angle between each stroke axis = $360^0/3 = 120^0$

Hence $\theta_1 = 0^0$, $\theta_2 = 120^0$, $\theta_3 = 240^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} = 240^0$, $\Phi_{Pr3} = 480^0$

$\Sigma \cos\Phi_{Pdi} = 3$

$\Sigma \cos \Phi_{Pri} = \cos(\Phi_{Pr1}) + \cos(\Phi_{Pr2}) + \cos(\Phi_{Pr3}) + \ldots\ldots\ldots\ldots \cos(\Phi_{Prn}) = 0$

Hence primary force due to direct crank (F_{Pd}) = $3*(m/2)*r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sdi} = -\theta_i$, , i.e. $\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -120^0$, $\Phi_{Sd3} = -240^0$

For reverse crank;

$\Phi_{Sri} = 3*\theta_i$, i.e. $\Phi_{Sr1} = 0^0$, $\Phi_{Sr2} = 360^0$, $\Phi_{Sr3} = 720^0$

$\Sigma\cos \Phi_{Sdi} = \cos \Phi_{Sd1} + \cos \Phi_{Sd2} + \cos \Phi_{Sd3} = 0$

$\Sigma\cos \Phi_{Sri} = \cos \Phi_{Sr1} + \cos \Phi_{Sr2} + \cos \Phi_{Sr3} = 3$

Secondary force due to direct crank (F_{Sd}) = $(m/2)*(r/n)*\omega^2* \Sigma\cos \Phi_{Sdi} = 0$

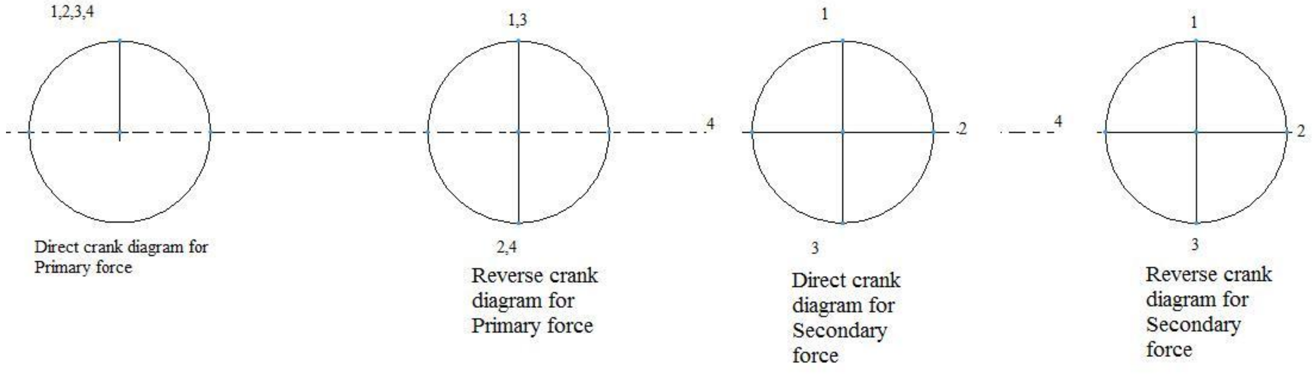
Secondary force due to reverse crank(F_{Sr}) = $3*(m/2)*(r/n)*\omega^2$

Total secondary unbalance force(F_S) = F_{Sr}

Total unbalanced force(F) = F_P+F_S

Total unbalanced couple = 0

R-4 engine analysis



Angle between each stroke axis = $360^0/4 = 90^0$

Hence $\theta_1 = 0^0$, $\theta_2 = 120^0$, $\theta_3 = 240^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} = 180^0$, $\Phi_{Pr3} = 360^0$ $\Phi_{Pr4} = 540^0$

$\Sigma \cos\Phi_{Pdi} = 4$

$\Sigma \cos \Phi_{Pri} = \cos(0^0) + \cos(180^0) + \cos(360^0) + \cos(540^0) = 0$

Hence primary force due to direct crank (F_{Pd}) = $4*(m/2)*r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sdi} = -\theta_i$, , i.e. $\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -90^0$, $\Phi_{Sd3} = -180^0$, $\Phi_{Sd4} = -270^0$

For reverse crank;

$\Phi_{Sri} = 3*\theta_i$, i.e. $\Phi_{Sr1} = 0^0$, $\Phi_{Sr2} = 270^0$, $\Phi_{Sr3} = 540^0$, $\Phi_{Sr4} = 810^0$

$\Sigma\cos \Phi_{Sdi} = \cos \Phi_{Sd1} + \cos \Phi_{Sd2} + \cos \Phi_{Sd3} + \cos \Phi_{Sd4} = 0$

$\Sigma\cos \Phi_{Sri} = \cos \Phi_{Sr1} + \cos \Phi_{Sr2} + \cos \Phi_{Sr3} + \cos \Phi_{Sr4} = 0$

Secondary force due to direct crank (F_{Sd}) = $(m/2)*(r/n)*\omega^2 * \Sigma\cos \Phi_{Sdi} = 0$

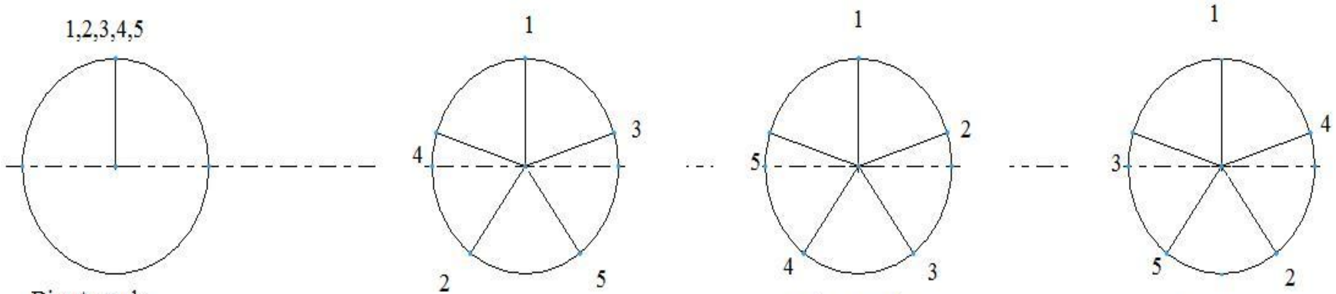
Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = $F_P + F_S = F_p$

Total unbalanced couple = 0

R-5 engine analysis



Direct crank diagram for Primary Force

Reverse crank diagram for Primary Force

Direct crank diagram for Secondary Force

Reverse crank diagram dor Secondary Force

Angle between each stroke axis = $360^0/5 = 72^0$

Hence $\theta_1=0^0$, $\theta_2= 72^0$, $\theta_3 = 144^0$, $\theta_4 = 216^0$,$\theta_5 = 288^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =144^0$, $\Phi_{Pr3} = 288^0$, $\Phi_{Pr4} = 432^0$ $\Phi_{Pr5} = 576^0$

$\Sigma \cos\Phi_{Pdi} = 5$

$\Sigma \cos \Phi_{Pri} = o$

Hence primary force due to direct crank (F_{Pd}) = $5*(m/2) *r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sdi} = -\theta_{i,}$, i.e. $\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -72^0$, $\Phi_{Sd3} = -144^0$, $\Phi_{Sd4} = -216^0$, $\Phi_{Sd5} = - 288^0$

For reverse crank;

$\Phi_{Sri} =3*\theta_i$, i.e. $\Phi_{Sr1} = 0^0$, $\Phi_{Sr2} = 216^0$, $\Phi_{Sr3} = 432^0$, $\Phi_{Sr4} = 648^0$, $\Phi_{Sr5} = 864^0$

$\Sigma\cos \Phi_{Sdi} = 0$

$\Sigma\cos \Phi_{Sri} = 0$

Secondary force due to direct crank (F_{Sd}) = 0

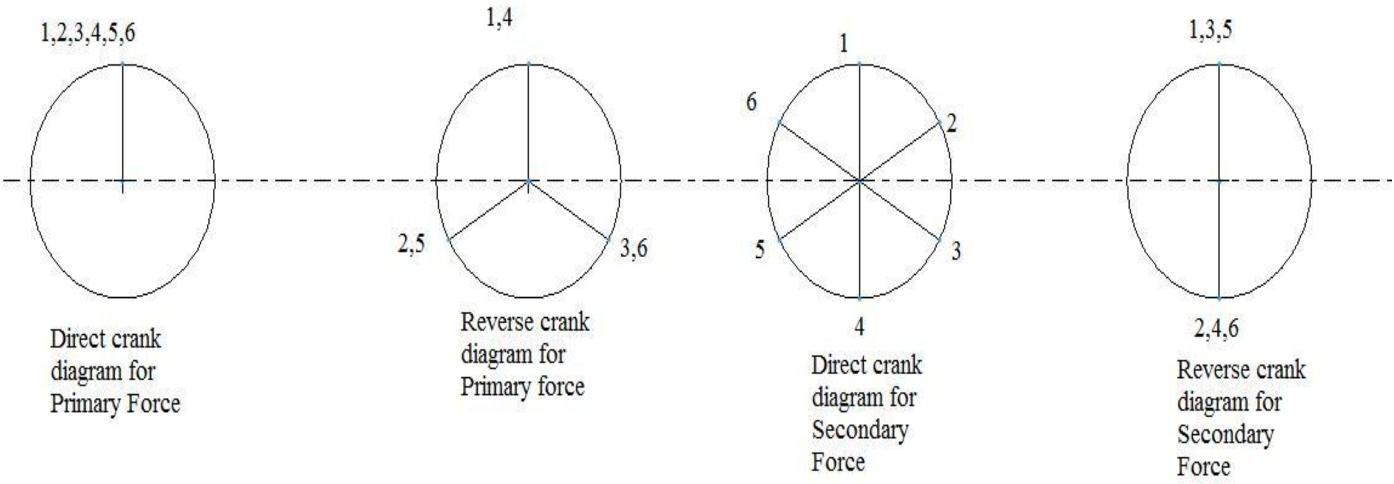
Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = F_P

Total unbalanced couple = 0

R-6 engine analysis



Angle between each stroke axis = $360^0/6 = 60^0$
Hence $\theta_1=0^0$, $\theta_2= 60^0$, $\theta_3 = 120^0$, $\theta_4 = 180^0$,$\theta_5 = 240^0$, $\theta_6 = 300^0$

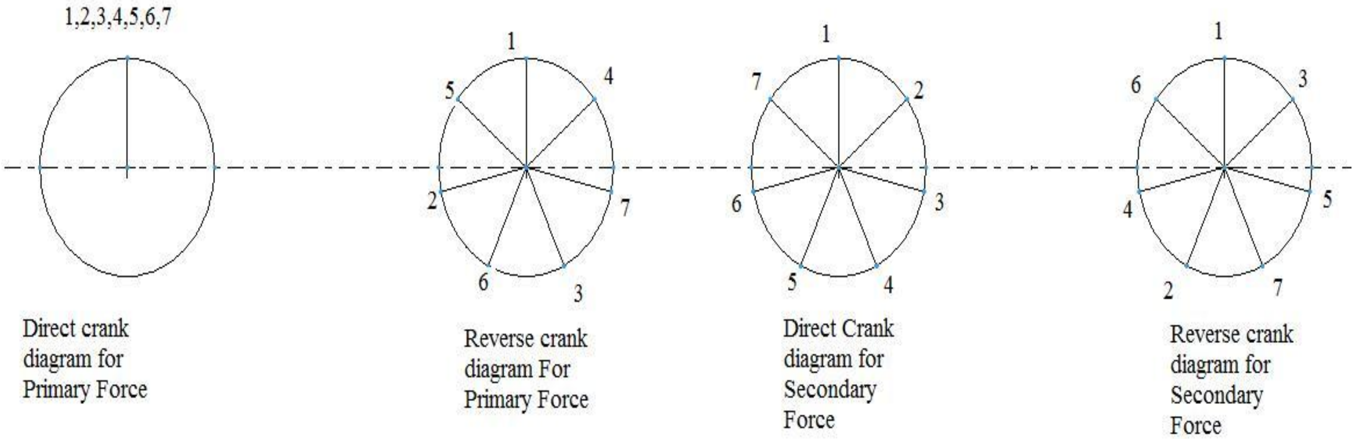
Primary unbalance force

For Direct crank ;
$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = 0^0$
For reverse crank;
$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =120^0$, $\Phi_{Pr3} = 240^0$, $\Phi_{Pr4} = 360^0$, $\Phi_{Pr5} = 480^0$, $\Phi_{Pr6} = 600^0$
$\Sigma \cos\Phi_{Pdi} = 6$
$\Sigma \cos \Phi_{Pri} = o$
Hence primary force due to direct crank (F_{Pd}) = $6*(m/2) *r*\omega^2$
Primary force due to reverse crank (F_{Pr}) = 0
Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;
$\Phi_{Sdi} = -\theta_{i,}$, i.e. $\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -60^0$, $\Phi_{Sd3} = -120^0$, $\Phi_{Sd4} = -180^0$, $\Phi_{Sd5} = - 240^0$, $\Phi_{Sd6} = - 300^0$
For reverse crank;
$\Phi_{Sri} =3*\theta_i$, i.e. $\Phi_{Sr1} = 0^0$, $\Phi_{Sr2} = 180^0$, $\Phi_{Sr3} = 360^0$, $\Phi_{Sr4} = 540^0$, $\Phi_{Sr5} = 720^0$, $\Phi_{Sr6} = 900^0$
$\Sigma\cos \Phi_{Sdi} = 0$
$\Sigma\cos \Phi_{Sri} = 0$
Secondary force due to direct crank (F_{Sd}) = 0
Secondary force due to reverse crank(F_{Sr}) = 0
Total secondary unbalance force(F_S) = 0
Total unbalanced force(F) = F_P
Total unbalanced couple = 0

R-7 engine analysis



Angle between each stroke axis = $360^0/7$

Hence $\theta_1=0^0$, $\theta_2= 360^0/7$, $\theta_3 = 2* 360^0/7$, $\theta_4 = 3* 360^0/7$, $\theta_5 =4*360^0/7$,$\theta_6= 5* 360^0/7$,$\theta_7 = 6* 360^0/7$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = \Phi_{Pd7} = 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =720^0/7$, $\Phi_{Pr3} = 1440^0/7$, $\Phi_{Pr4} = 2160^0/7$, $\Phi_{Pr5} = 2880^0/7$, $\Phi_{Pr6} = 3600^0/7$ $\Phi_{Pr7} = 4320^0/7$

$\Sigma \cos\Phi_{Pdi} = 7$

$\Sigma \cos \Phi_{Pri} = 0$

Hence primary force due to direct crank (F_{Pd}) =7* (m/2) *r*ω^2

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} = -360^0/7$, $\Phi_{Sd3} =-720^0/7$,$\Phi_{Sd4}= -1080^0/7$,$\Phi_{Sd6}= -1800^0/7$,$\Phi_{Sd5}= -1440^0/7$$\Phi_{Sd7}=-2160^0/7$

For reverse crank;

$\Phi_{Sr1} = 0^0$, $\Phi_{Sr2}= 1080^0/7$,$\Phi_{Sr3} =2160^0/7$,$\Phi_{Sr4}=3240^0/7$,$\Phi_{Sr5}=4320^0/7$,$\Phi_{Sr6}=5400^0/7$,$\Phi_{Sr7}=6480^0/7$

$\Sigma\cos \Phi_{Sdi} = 0$

$\Sigma\cos \Phi_{Sri} = 0$

Secondary force due to direct crank (F_{Sd}) = 0

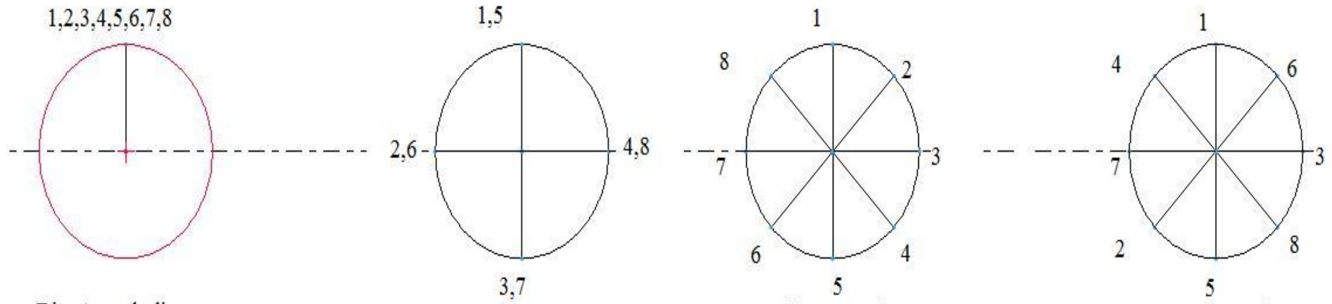
Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = F_P

Total unbalanced couple = 0

R-8 engine analysis



Direct crank diagram for Primary Force

Reverse Crank diagram for Primary Force

direct Crank diagram for Secondary Force

Reverse crank diagram for Secondary Force

Angle between each stroke axis = $360^0/8 = 45^0$

Hence $\theta_1=0^0$, $\theta_2= 45^0$, $\theta_3 = 90^0$, $\theta_4 = 135^0$, $\theta_5 = 180^0$,$\theta_6 = 225^0$, $\theta_7 = 270^0$, $\theta_8 = 315^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = \Phi_{Pd7}= \Phi_{Pd8}= 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =90^0$, $\Phi_{Pr3} = 180^0$, $\Phi_{Pr4} = 270^0$, $\Phi_{Pr5} =360^0$, $\Phi_{Pr6} = 450^0$, $\Phi_{Pr7} = 540^0$, $\Phi_{Pr8} =630^0$

$\Sigma \cos\Phi_{Pdi} = 8$

$\Sigma \cos \Phi_{Pri} = 0$

Hence primary force due to direct crank (F_{Pd}) = $8*(m/2) *r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sd1} = 0^0$, $\Phi_{Sd2} =-45^0$,$\Phi_{Sd3} =-90^0$,$\Phi_{Sd4} =-135^0$,$\Phi_{Sd5}=-180^0$,$\Phi_{Sd6}=-225^0$, $\Phi_{Sd7}=-270^0$, $\Phi_{Sd8}=-315^0$

For reverse crank;

$\Phi_{Sr1} = 0^0$,$\Phi_{Sr2}=135^0$,$\Phi_{Sr3}=270^0$,$\Phi_{Sr4}=405^0$,$\Phi_{Sr5}=540^0$,$\Phi_{Sr6}=675^0$, $\Phi_{Sr7}=810^0$, $\Phi_{Sr8}=945^0$

$\Sigma\cos \Phi_{Sdi} = 0$

$\Sigma\cos \Phi_{Sri} = 0$

Secondary force due to direct crank (F_{Sd}) = 0

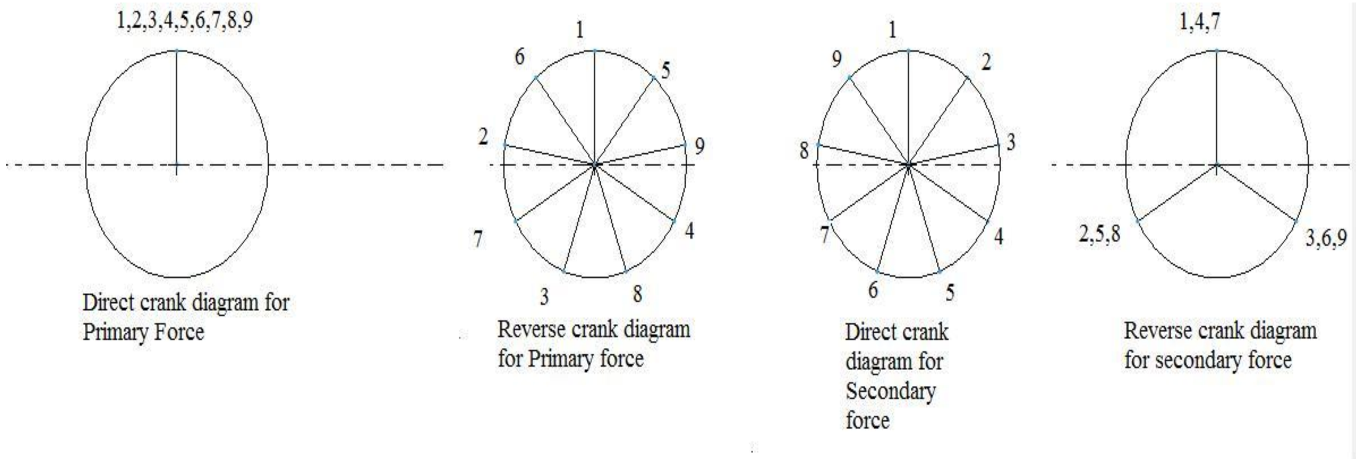
Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = F_P

Total unbalanced couple = 0

R-9 engine analysis



Angle between each stroke axis = $360^0/9 = 40^0$

Hence $\theta_1=0^0$, $\theta_2= 40^0$, $\theta_3=80^0$,$\theta_4= 120^0$, $\theta_5 = 160^0$,$\theta_6 = 200^0$, $\theta_7 = 240^0$, $\theta_8 = 280^0$, $\theta_9=320^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = \Phi_{Pd7}= \Phi_{Pd8}= \Phi_{Pd9}= 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =80^0$, $\Phi_{Pr3} = 160^0$, $\Phi_{Pr4}=240^0$,$\Phi_{Pr5} =320^0$,$\Phi_{Pr6}=400^0$,$\Phi_{Pr7}=480^0$,$\Phi_{Pr8}=560^0$,$\Phi_{Pr9}=640^0$

$\Sigma \cos\Phi_{Pdi} = 9$

$\Sigma \cos \Phi_{Pri} =0$

Hence primary force due to direct crank (F_{Pd}) = $9*(m/2) *r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sd1}= 0^0$,$\Phi_{Sd2}=-40^0$,$\Phi_{Sd3}=-80^0$,$\Phi_{Sd4}=-120^0$,$\Phi_{Sd5}=-160^0$,$\Phi_{Sd6}=-200^0$,$\Phi_{Sd7}=-240^0$,$\Phi_{Sd8}=-280^0$, $\Phi_{Sd9}=-320^0$

For reverse crank;

$\Phi_{Sr1}= 0^0$,$\Phi_{Sr2}=120^0$,$\Phi_{Sr3}=240^0$,$\Phi_{Sr4}=360^0$,$\Phi_{Sr5}=480^0$,$\Phi_{Sr6}=600^0$,$\Phi_{Sr7}=720^0$,$\Phi_{Sr8}=840^0$, $\Phi_{Sr9}=960^0$

$\Sigma\cos \Phi_{Sdi} = 0$

$\Sigma\cos \Phi_{Sri} = 0$

Secondary force due to direct crank (F_{Sd}) = 0

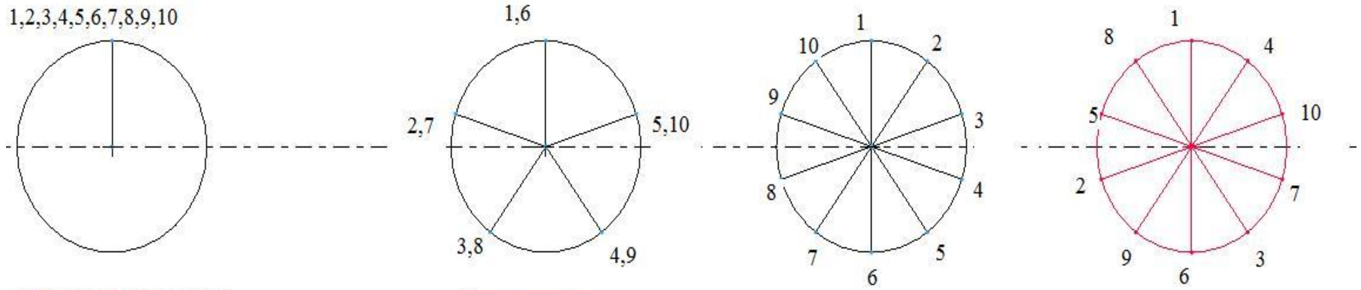
Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = F_P

Total unbalanced couple = 0

R-10 engine analysis



Direct crank diagram for Primary Force

Reverse crank diagram for Primary Force

Direct crank diagram for Secondary force

Reverse crank diagram for Secondary force

Angle between each stroke axis = $360^0/10 = 36^0$

Hence $\theta_1=0^0$, $\theta_2= 36^0$, $\theta_3=72^0$,$\theta_4= 108^0$, $\theta_5 = 144^0$,$\theta_6 = 180^0$, $\theta_7 = 216^0$, $\theta_8 = 252^0$, $\theta_9=288^0$, $\theta_{10}=324^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = \Phi_{Pd7}= \Phi_{Pd8}= \Phi_{Pd9}= \Phi_{Pd10}=0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =72^0$,$\Phi_{Pr3}= 144^0$,$\Phi_{Pr4}=216^0$,$\Phi_{Pr5}=288^0$,$\Phi_{Pr6}=360^0$,$\Phi_{Pr7}=432^0$,$\Phi_{Pr8}=504^0$,$\Phi_{Pr9}=576^0$, $\Phi_{Pr10}=648^0$

$\Sigma \cos\Phi_{Pdi} = 10$

$\Sigma \cos \Phi_{Pri} =0$

Hence primary force due to direct crank (F_{Pd}) = $10*(m/2) *r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sd1}=0^0$,$\Phi_{Sd2}=-36^0$,$\Phi_{Sd3}=-72^0$,$\Phi_{Sd4}=-108^0$,$\Phi_{Sd5}=-144^0$,$\Phi_{Sd6}=-180^0$,$\Phi_{Sd7}=-216^0$,$\Phi_{Sd8}=-252^0$,$\Phi_{Sd9}=-288^0$, $\Phi_{Sd10}=-324^0$

For reverse crank;

$\Phi_{Sr1}= 0^0$,$\Phi_{Sr2}=108^0$,$\Phi_{Sr3}=216^0$,$\Phi_{Sr4}=324^0$,$\Phi_{Sr5}=432^0$,$\Phi_{Sr6}=540^0$,$\Phi_{Sr7}=648^0$,$\Phi_{Sr8}=756^0$, $\Phi_{Sr9}=864^0$, $\Phi_{Sr10}=972^0$

$\Sigma\cos \Phi_{Sdi} = 0$

$\Sigma\cos \Phi_{Sri} = 0$

Secondary force due to direct crank (F_{Sd}) = 0

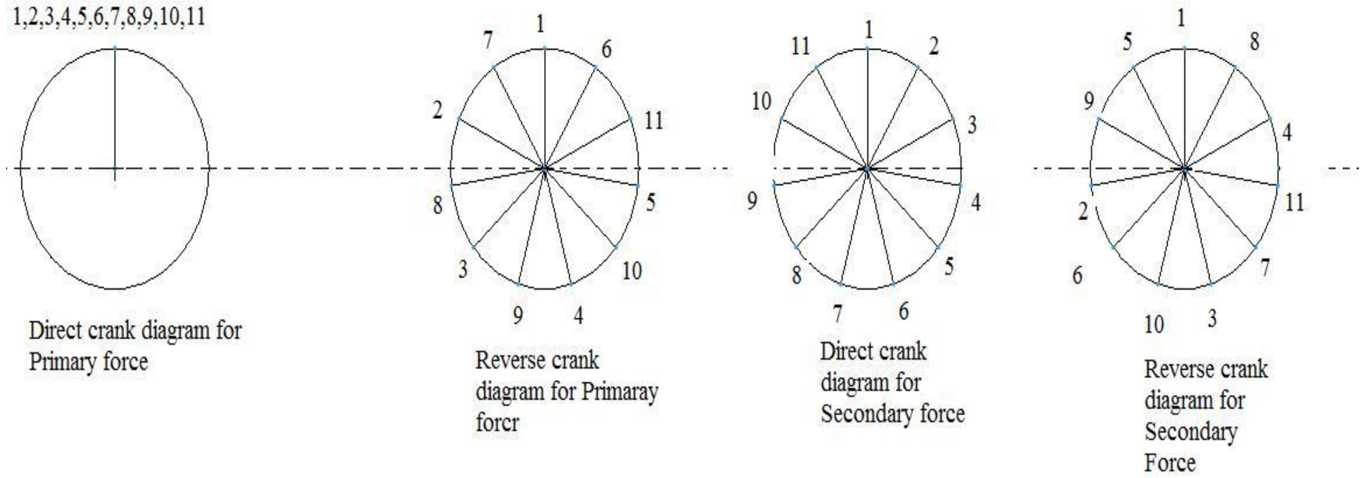
Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = F_P

Total unbalanced couple = 0

R-11 engine analysis



Angle between each stroke axis = $360^0/11$
Hence $\theta_1=0^0$,$\theta_2=360^0/11$,$\theta_3 = 2*360^0/11$,$\theta_4=3*360^0/11$,$\theta_5=4*360^0/11$,$\theta_6=5*360^0/11$,$\theta_7= 6* 360^0/11$,$\theta_8= 7*360^0/11$,$\theta_9= 8*360^0/11$,$\theta_9= 8*360^0/11$,$\theta_{10}= 9*360^0/11$,$\theta_{11}= 10*360^0/11$

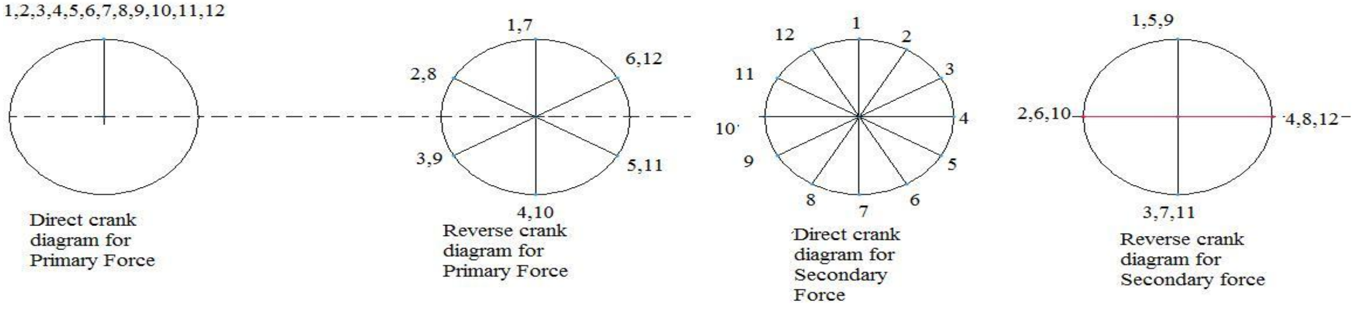
Primary unbalance force

For Direct crank ;
$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = \Phi_{Pd7} = \Phi_{Pd8} = \Phi_{Pd9} = \Phi_{Pd10 =} \Phi_{Pd11} =0^0$
For reverse crank;
$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =720^0/11$,$\Phi_{Pr3} = 1440^0/11$, $\Phi_{Pr4} = 2160^0/11$,$\Phi_{Pr5} = 2880^0/11$,$\Phi_{Pr6}=3600^0/11$, $\Phi_{Pr7} = 4320^0/11$, $\Phi_{Pr8} = 5040^0/11$, $\Phi_{Pr9} = 57600^0/11$, $\Phi_{Pr10} = 6480^0/11$, $\Phi_{Pr11} = 7200^0/11$
$\Sigma \cos\Phi_{Pdi} = 11$
$\Sigma \cos \Phi_{Pri} = 0$
Hence primary force due to direct crank (F_{Pd}) =11* (m/2) *r*ω^2
Primary force due to reverse crank (F_{Pr}) = 0
Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;
$\Phi_{Sd1} = 0^0$,$\Phi_{Sd2} = -360^0/11$,$\Phi_{Sd3} = -720^0/11$,$\Phi_{Sd4}= -1080^0/11$,$\Phi_{Sd6}= -1800^0/11$,$\Phi_{Sd5}= -1440^0/11$$\Phi_{Sd7}= -2160^0/11$, $\Phi_{Sd8}= -2520^0/11$, $\Phi_{Sd9}= -2880^0/11$, $\Phi_{Sd10}= -3240^0/11$, $\Phi_{Sd11}= -3600^0/11$
For reverse crank;
$\Phi_{Sr1} = 0^0$,$\Phi_{Sr2}= 1080^0/11$,$\Phi_{Sr3} =2160^0/11$,$\Phi_{Sr4}=3240^0/11$,$\Phi_{Sr5}=4320^0/11$,$\Phi_{Sr6}=5400^0/11$,$\Phi_{Sr7}=6480^0/11$, $\Phi_{Sr8}=7560^0/11$, $\Phi_{Sr9}=8640^0/11$, $\Phi_{Sr10}= 9720^0/11$, $\Phi_{Sr7}=10800^0/11$
$\Sigma\cos \Phi_{Sdi} = 0$
$\Sigma\cos \Phi_{Sri} = 0$
Secondary force due to direct crank (F_{Sd}) = 0
Secondary force due to reverse crank(F_{Sr}) = 0
Total secondary unbalance force(F_S) = 0
Total unbalanced force(F) = F_P
Total unbalanced couple = 0

R-12 engine analysis



Angle between each stroke axis = $360^0/12 = 30^0$

Hence $\theta_1=0^0$, $\theta_2= 30^0$, $\theta_3=60^0$,$\theta_4= 90^0$, $\theta_5 = 120^0$,$\theta_6 = 150^0$, $\theta_7 = 180^0$, $\theta_8 = 210^0$, $\theta_9=240^0$, $\theta_{10}=270^0$, $\theta_{11}=300^0$, $\theta_{12}=330^0$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4} = \Phi_{Pd5} = \Phi_{Pd6} = \Phi_{Pd7}= \Phi_{Pd8}= \Phi_{Pd9}= \Phi_{Pd10}= \Phi_{Pd11} = \Phi_{Pd12} =0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =60^0$,$\Phi_{Pr3}= 120^0$,$\Phi_{Pr4}=180^0$,$\Phi_{Pr5}=240^0$,$\Phi_{Pr6}=300^0$,$\Phi_{Pr7}=360^0$,$\Phi_{Pr8}=420^0$,$\Phi_{Pr9}=480^0$, $\Phi_{Pr10}=540^0$, $\Phi_{Pr11}=600^0$, $\Phi_{Pr12} = 660^0$

$\Sigma \cos\Phi_{Pdi} = 12$

$\Sigma \cos \Phi_{Pri} =0$

Hence primary force due to direct crank (F_{Pd}) = $12*(m/2) *r*\omega^2$

Primary force due to reverse crank (F_{Pr}) = 0

Hence primary unbalance force (F_P) = F_{Pd}

Secondary unbalance force

For direct crank;

$\Phi_{Sd1}=0^0$,$\Phi_{Sd2}=-30^0$,$\Phi_{Sd3}=-60^0$,$\Phi_{Sd4}=-90^0$,$\Phi_{Sd5}=-120^0$,$\Phi_{Sd6}=-150^0$,$\Phi_{Sd7}=-180^0$,$\Phi_{Sd8}=-210^0$,$\Phi_{Sd9}=-240^0$, $\Phi_{Sd10}=-270^0$, $\Phi_{Sd11}=-300^0$, $\Phi_{Sd12}=-330^0$

For reverse crank;

$\Phi_{Sr1}= 0^0$,$\Phi_{Sr2}=90^0$,$\Phi_{Sr3}=180^0$,$\Phi_{Sr4}=270^0$,$\Phi_{Sr5}=360^0$,$\Phi_{Sr6}=450^0$,$\Phi_{Sr7}=540^0$,$\Phi_{Sr8}=630^0$, $\Phi_{Sr9}=720^0$, $\Phi_{Sr10}=810^0$, $\Phi_{Sr11}=900^0$, $\Phi_{Sr12}=990^0$

$\Sigma\cos \Phi_{Sdi} = 0$

$\Sigma\cos \Phi_{Sri} = 0$

Secondary force due to direct crank (F_{Sd}) = 0

Secondary force due to reverse crank(F_{Sr}) = 0

Total secondary unbalance force(F_S) = 0

Total unbalanced force(F) = F_P

Total unbalanced couple = 0

The above analytical analysis can be done for radial engines with more no. Of cylinders but calculation will be more hence computer aided analysis is preferred to minimize time and calculation. A c programme is generated for the above purpose.

C PROGRAM FOR DYNAMIC ANALYSIS OF MULTI-CYLINDER RADIAL ENGINES

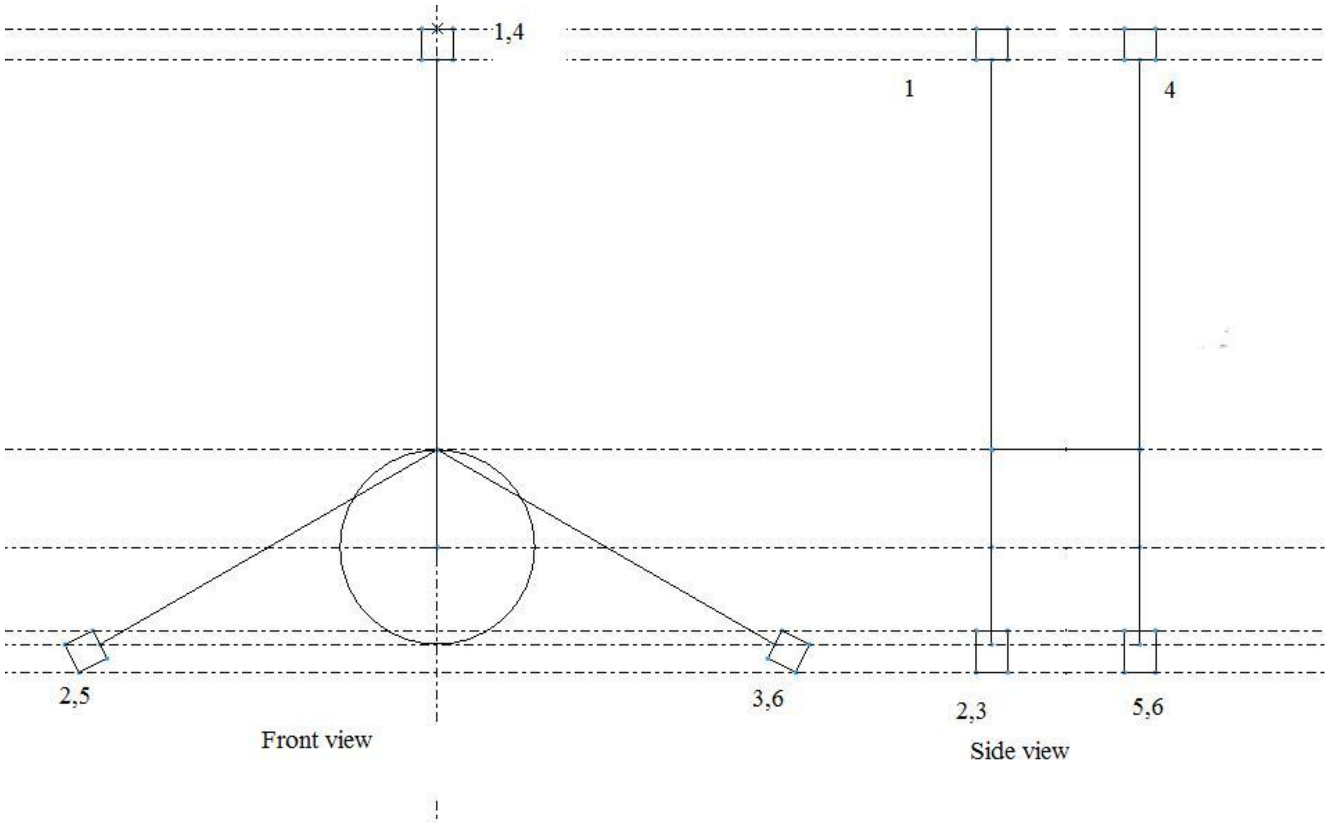
```
#include<stdio.h>
#include<conio.h>
#include<math.h>
const double PI = 3.14159265;
int main()
{
	float
i,a,n,r,m,w,l,N,angle,ang1[20],ang2[20],s=0,s1=0,ang3[20],s2=0,fp,fpr,ang[20],fpd,fsr,fsd,f,fs;
	printf("enter no of cylinders :");scanf("%f",&i);printf("\n");
	printf("enter the length of each stroke(in metre) :");scanf("%f",&a);printf("\n");
	printf("enter mass of each cylinder (in kg) :");scanf("%f",&m);printf("\n");
	printf("enter length of connecting rod(in metre) :");scanf("%f",&l);printf("\n");
	printf("enter rpm of the engine :");scanf("%f",&N);printf("\n");
	r=a/2;n=l/r;printf("%f %f\n",r,n);
	w=(2*PI*N)/60;printf("%f\n",w);
	angle=360/i;ang[0]=0;ang1[0]=0;ang2[0]=0;//printf("%f\n",angle);
	for(int j=1;j<=i;j++)
	{
		ang[j]=ang[j-1]+angle;ang2[j]=-ang[j];  ang3[j]=3*ang[j];
		ang1[j]=2*ang[j];s=s+cos(ang1[j-1]*PI/180);s1=s1+cos(ang2[j-
1]*PI/180);s2=s2+cos(ang3[j-1]*PI/180);
		printf("%f %f\n",ang[j-1],cos(ang[j-1]*PI/180));
	}
	//printf("%f %f \n",ang[j],cos(ang[j]*PI/180));
	//s=s+cos(ang1[11]*PI/180);s1=s1+cos(ang2[11]*PI/180);s2=s2+cos(ang3[11]*PI/180);
	printf("%f %f %f\n",s,s1,s2);
	fpd=i*.5*m*r*pow(w,2);printf("total primary force for direct crank %f\n",fpd);
	fpr=m*r*pow(w,2)*s/2;printf("total primary force for reverse crank %f\n",fpr);
	fp=fpd+fpr;printf("total primary force %f\n",fp);
	fsd=m*(r/n)*pow(w,2)*s1/2;printf("total secondary force for direct crank %f\n",fsd);
	fsr=m*(r/n)*pow(w,2)*s2/2;printf("total secondary force for reverse crank %f\n",fsr);
	fs=fsd+fsr;printf("total secondary force %f\n",fs);
	f=fp+fs;printf("total unbalanced force %f\n",f);
getch();
return 0;
}
```

CHAPTER # 6

THEORETICAL ANALYSIS OF BALANCING OF MULTI-CYLINDER MULTIPLE ROW RADIAL ENGINES

In aero engines generally radial engines are connected axially with a common crank shaft as a result whole unit works as one configuration. In general practice two rows of radial engines are used. Maximum four rows are practically used.

2- Row R-3 engine



Distance between each row "l"

Referring analysis of radial engine of chapter 5

Total unbalanced primary force of an individual R-3 engine = $3*(m/2)*r\omega^2$

Total unbalanced secondary force for an individual R-3 engine = $3*(m/2)*(r/n)\omega^2$

Hence total Primary force for 2-Row R-3 engine(F_P) = $2*3*(m/2)*r\omega^2$

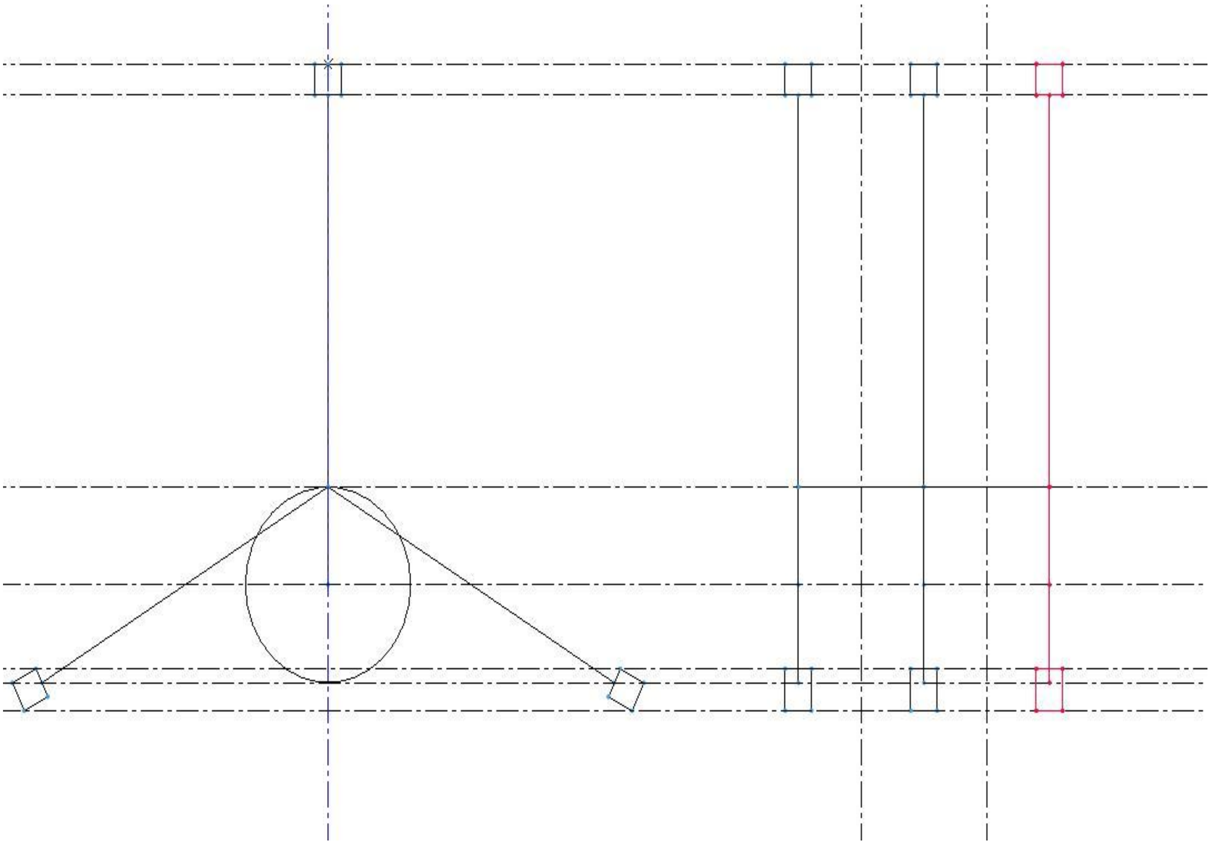
Total secondary force for 2- Row R-3 engine (F_S) = $2*= 3*(m/2)*(r/n)\omega^2$

Total unbalanced force (F) = F_P+F_S

Total primary couple (C_P) = 0

Total secondary couple (C_S) = 0

3- Row R-3 engine analysis



Distance between each row "l"

Referring analysis of radial engine of chapter 5

Total unbalanced primary force of an individual R-3 engine = $3*(m/2)*r\omega^2$

Total unbalanced secondary force for an individual R-3 engine = $3*(m/2)*(r/n)\omega^2$

Hence total Primary force for 3-Row R-3 engine(F_P) = $3*3*(m/2)*r\omega^2$

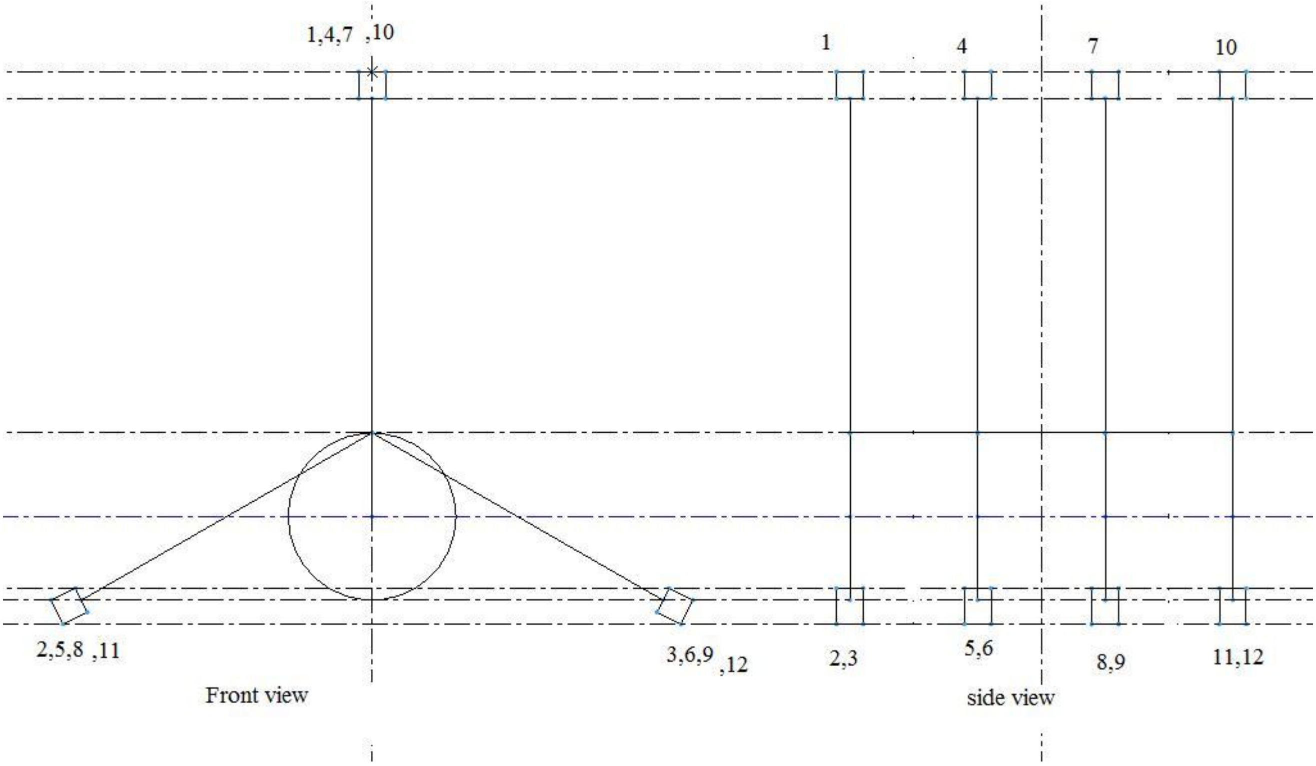
Total secondary force for 3- Row R-3 engine (F_S) = $3*3*(m/2)*(r/n)\omega^2$

Total unbalanced force (F) = F_P+F_S

Total primary couple (C_P) = 0

Total secondary couple (C_S) = 0

4- Row R-3 engine analysis



Distance between each row “l”

Referring analysis of radial engine of chapter 5

Total unbalanced primary force of an individual R-3 engine = $3*(m/2)*r\omega^2$

Total unbalanced secondary force for an individual R-3 engine = $3*(m/2)*(r/n)\omega^2$

Hence total Primary force for 4-Row R-3 engine(F_P) = $4*3*(m/2)*r\omega^2$

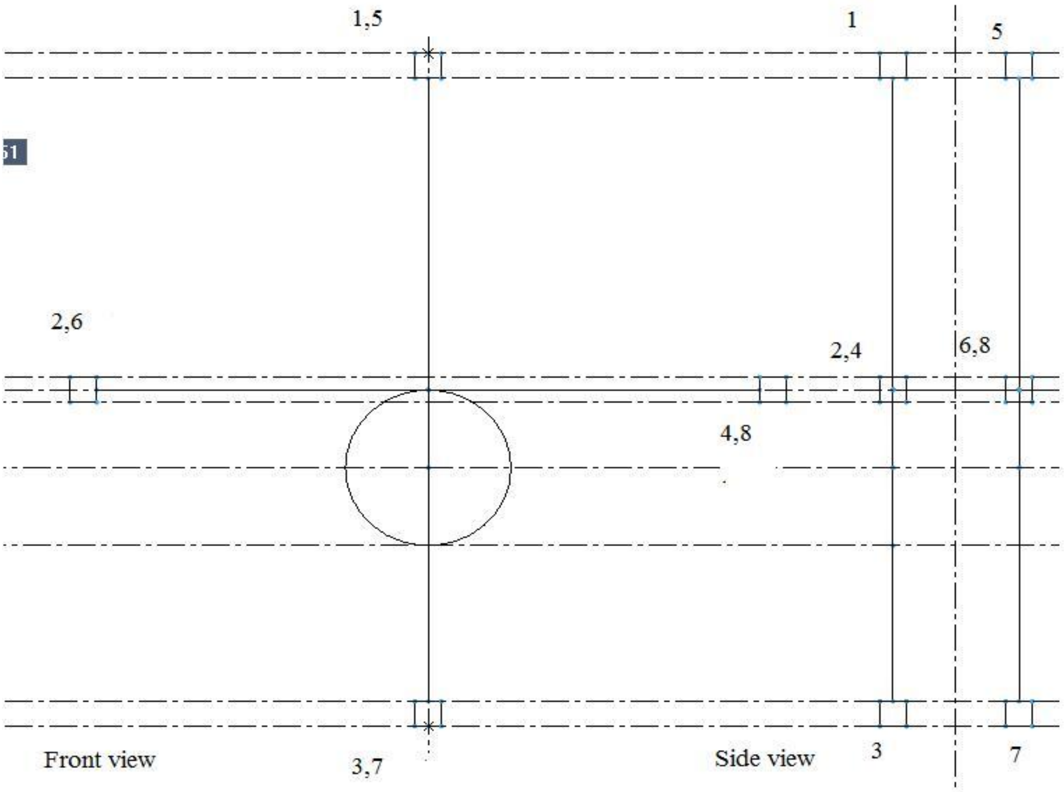
Total secondary force for 4- Row R-3 engine (F_S) = $4*3*(m/2)*(r/n)\omega^2$

Total unbalanced force (F) = F_P+F_S

Total primary couple (C_P) = 0

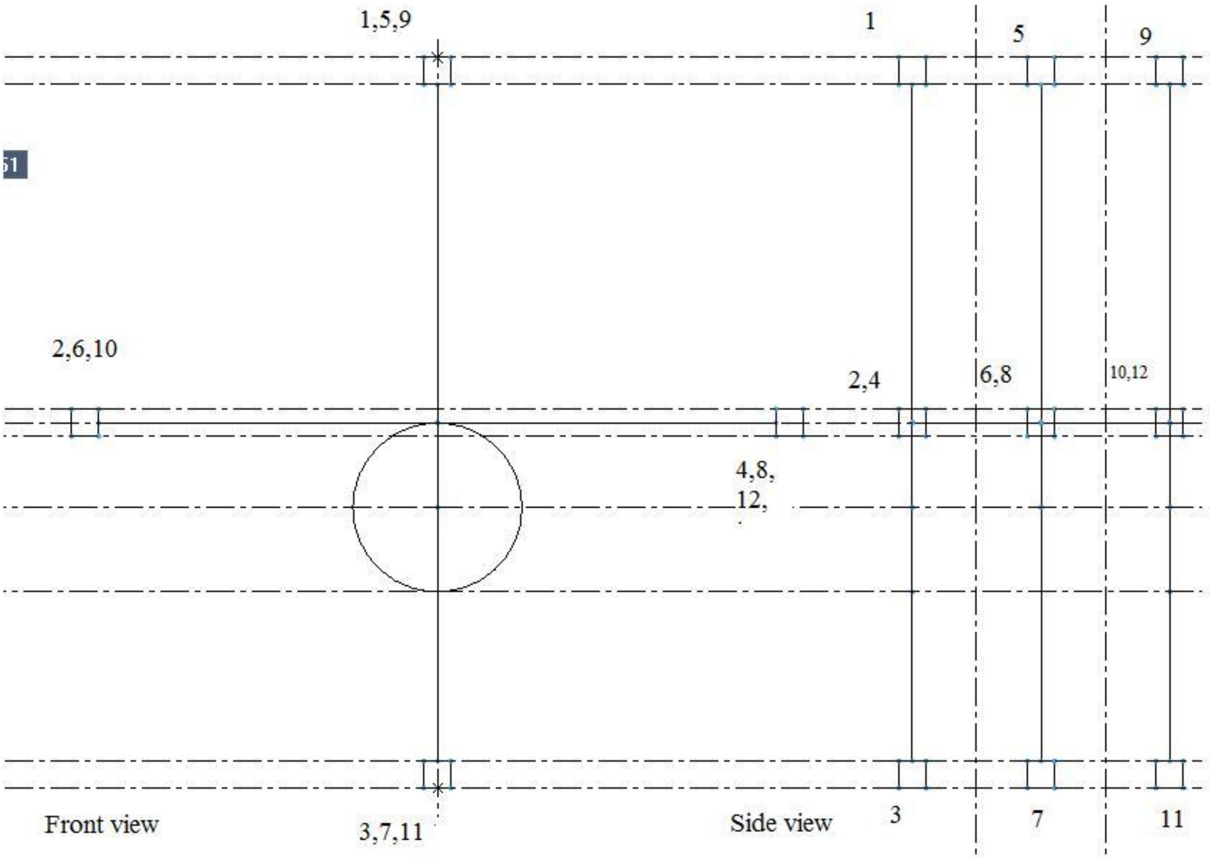
Total secondary couple (C_S) = 0

2- Row R-4 engine analysis



Distance between each row "l"
Referring analysis of radial engine of chapter 5
Total unbalanced primary force of an individual R-4 engine = $4*(m/2)*r\omega^2$
Total unbalanced secondary force for an individual R-4 engine = 0
Hence total Primary force for 2-Row R-4 engine(F_P) = $2*4*(m/2)*r\omega^2$
Total secondary force for 2- Row R-4 engine (F_S) = 0
Total unbalanced force (F) = F_P+F_S
Total primary couple (C_P) = 0
Total secondary couple (C_S) = 0

3-Row R-4 engine analysis



Distance between each row "l"

Referring analysis of radial engine of chapter 5

Total unbalanced primary force of an individual R-4 engine = $4*(m/2)*r\omega^2$

Total unbalanced secondary force for an individual R-4 engine = 0

Hence total Primary force for 3-Row R-4 engine(F_P) = $3*4*(m/2)*r\omega^2$

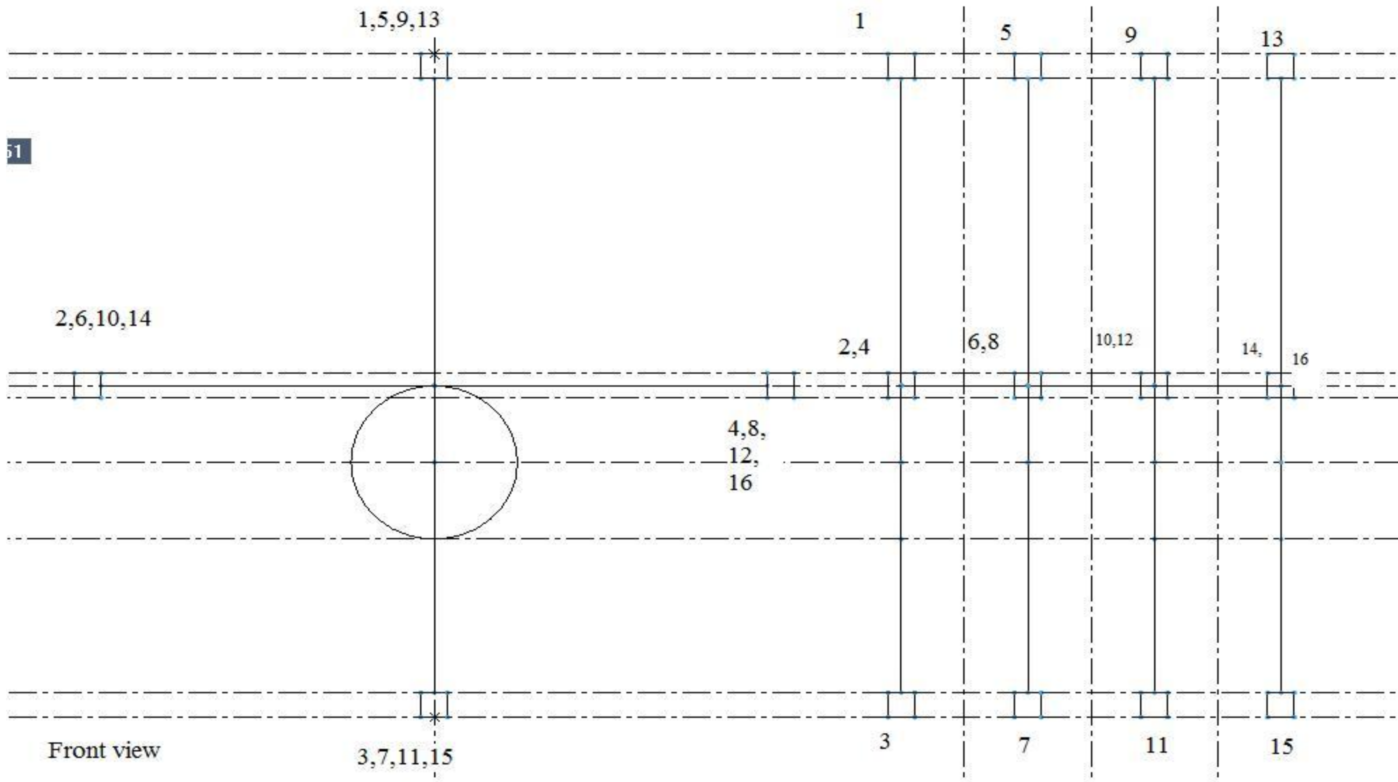
Total secondary force for 3- Row R-4 engine (F_S) = 0

Total unbalanced force (F) = F_P+F_S

Total primary couple (C_P) = 0

Total secondary couple (C_S) = 0

4-Row R-4 engine analysis



Distance between each row “l”

Referring analysis of radial engine of chapter 5

Total unbalanced primary force of an individual R-4 engine = $4*(m/2)*r\omega^2$

Total unbalanced secondary force for an individual R-4 engine = 0

Hence total Primary force for 4-Row R-4 engine(F_P) = $4*4*(m/2)*r\omega^2$

Total secondary force for 4- Row R-4 engine (F_S) = 0

Total unbalanced force (F) = F_P+F_S

Total primary couple (C_P) = 0

Total secondary couple (C_S) = 0

j- Row R-n engine analysis

Referring to chapter 5

Angle between each stroke axis = $360^0/n$

Hence $\theta_1=0^0$, $\theta_2= 360^0/n$, $\theta_3 = 2* 360^0/n$, $\theta_4 = 3* 360^0/n$,............................ $\theta_n = (n-1)* 360^0/n$

Primary unbalance force

For Direct crank ;

$\Phi_{Pd1} = \Phi_{Pd2} = \Phi_{Pd3} = \Phi_{Pd4}$ =...........................= $\Phi_{Pdn} = 0^0$

For reverse crank;

$\Phi_{Pr1} = 0^0$, $\Phi_{Pr2} =2* 360^0/n$, $\Phi_{Pr3} = 2*(2* 360^0/n)$, ... $\Phi_{Prn} = 2*\{(n-1)*360^0/n\}$

Hence $\Phi_{Pri} = 2*\theta_i$

$\Sigma \cos\Phi_{Pdi} = n$

$\Sigma \cos \Phi_{Pri} = \cos(\Phi_{Pr1}) + \cos(\Phi_{Pr2}) + \cos (\Phi_{Pr3})$ +....................$\cos(\Phi_{Prn})$

Hence primary force due to direct crank (F_{Pd}) = (m/2) *r*ω^2*(Σ cosΦ_{Pdi})
Primary force due to reverse crank (F_{Pr}) = (m/2)*r*ω^2*(Σ cosΦ_{Pri})
Hence primary unbalance force (F_P) = F_{Pd} +F_{Pr}

Secondary unbalance force

For direct crank;
Φ_{Sdi} = -θ_i, , i.e. Φ_{Sd1} = 0^0 , Φ_{Sd2} = -360^0/n , Φ_{Sd3} = -2* 360^0/n , ... Φ_{Sdn} = - (n-1)*360^0/n
For reverse crank;
Φ_{Sri} =3*θ_i , i.e. Φ_{Sr1} = 0^0, Φ_{Sr2} = 3*360^0/n , Φ_{Sr3} = 3*(2*360^0/n) ,............. Φ_{Srn} = 3*{(n-1)*360^0/n}
Σcos Φ_{Sdi} = cos Φ_{Sd1} +cos Φ_{Sd2}+cos Φ_{Sd3}+....................cos Φ_{Sdn}
Σcos Φ_{Sri} = cos Φ_{Sr1}+ cos Φ_{Sr2}+cos Φ_{Sr3}+.......................cos Φ_{Srn}
Secondary force due to direct crank (F_{Sd}) = (m/2)*(r/n)*ω^2* Σcos Φ_{Sdi}
Secondary force due to reverse crank(F_{Sr}) = (m/2)*(r/n)*ω^2* Σcos Φ_{Sri}
Total secondary unbalance force(F_S) = F_{Sd}+F_{Sr}

Hence total Primary force for j-Row R-n engine(F_P) = j*[(m/2) *r*ω^2*(Σ cosΦ_{Pdi}) + (m/2)*r*ω^2*(Σ cosΦ_{Pri})]
Total secondary force for j- Row R-n engine (F_S) = j* [(m/2)*(r/n)*ω^2* Σcos Φ_{Sdi} + (m/2)*(r/n)*ω^2* Σcos Φ_{Sri})
Total unbalanced force (F) = F_P+F_S
Total primary couple (C_P) = 0
Total secondary couple (C_S) = 0
The above analytical analysis can be done for combined row radial engines with more no. Of cylinders but calculation will be more hence computer aided analysis is preferred for time and calculation minimization. A c programme is generated for the above purpose.

C PROGRAM FOR DYNAMIC ANALYSIS OF MULTI-CYLINDER MULTIPLE ROW RADIAL ENGINES

```
# include <stdio.h>
# include <conio.h>
# include <math.h>
const double PI = 3.14159265;
int main()
{
        float
i,j,k,a,n,R,m,w,l,L,N,angle,ang1[20],ang2[20],s=0,s1=0,ang3[20],s2=0,fp,fpr,ang[20],fpd,fsr,
fsd,f,fs;
         printf("enter no of cylinders :");scanf("%f",&i);printf("\n");
          printf("enter no of rows :");scanf("%f",&j);printf("\n");
          printf("enter mass of each cylinder (in kg) :");scanf("%f",&m);printf("\n");
         printf("enter the length of each stroke(in metre) :");scanf("%f",&a);printf("\n");
         printf("enter length of connecting rod(in metre) :");scanf("%f",&L);printf("\n");
         printf("enter rpm of the engine :");scanf("%f",&N);printf("\n");
```

```
	printf(" enter the distance between two consecutive bank of radial cylinder:"); scanf("%f",&l); printf ("\n");
	R=a/2;n=L/R;printf("%f %f\n",R,N);
	w=(2*PI*N)/60;printf("%f\n",w);
	k= i/j;
	angle=360/k;ang[0]=0;ang1[0]=0;ang2[0]=0;//printf("%f\n",angle);
	for(int p=1;p<=k;p++)
	{
		ang[p]=ang[p-1]+angle;ang2[p]=-ang[p];  ang3[p]=3*ang[p];
		ang1[p]=2*ang[p];s=s+cos(ang1[p-1]*PI/180);s1=s1+cos(ang2[p-1]*PI/180);s2=s2+cos(ang3[p-1]*PI/180);
		printf("%f %f\n",ang[p-1],cos(ang[p-1]*PI/180));
	}
	//printf("%f %f \n",ang[p],cos(ang[p]*PI/180));

//s=s+cos(ang1[11]*PI/180);s1=s1+cos(ang2[11]*PI/180);s2=s2+cos(ang3[11]*PI/180);
	printf("%f %f %f\n",s,s1,s2);
	fpd=i*.5*m*R*pow(w,2);printf("total primary force for direct crank %f\n",fpd);
	fpr=j*m*R*pow(w,2)*s/2;printf("total primary force for reverse crank %f\n",fpr);
	fp=fpd+fpr;printf("total primary force %f\n",fp);
	fsd=j*m*R*pow(w,2)*s1*0.5/n;printf("total secondary force for direct crank %f\n",fsd);
	fsr=j*m*R*pow(w,2)*s2*0.5/n;printf("total secondary force for reverse crank %f\n",fsr);
	fs=fsd+fsr;printf("total secondary force %f\n",fs);
	f=fp+fs;printf("total unbalanced force %f\n",f);
getch();
return 0;
}
```

CHAPTER # 7

RESULTS AND DISCUSSION

It is assumed that the mass of the cylinder is 2.4 kg
RPM of the engine is 2000
Length of each stroke 0.16 m
Length of connecting rod 0.24 m
Vee angle 60^0
Angle between 1^{st} cylinder and Vee – axis 0^0
Distance between two consecutive cylinders 0.1 m
Now varying no. Of cylinders present in the combination unbalanced force and couple was calculated
FOR V-2 ENGINE

```
Select C:\Users\PAPUN\Desktop\Untitled1.exe

Enter RPM of Engine      :2000

Enter V Angle    :60

Enter Angle between 1st cyl and V-axis   :0

Enter Distance betwwen two consecutiv cyl bank  :0.1

TC= 1.000000
TS= 0.000000
TTC= 1.000000
TTS= 0.000000
AOC= 0.000000
AOCC= 0.000000
AOS= 0.000000
AOSS= 0.000000
fpx= 12633.093750
fpy= 0.000000
fsx= 2431.239990
fsy= 0.000000
fp= 12633.093750
fs= 2431.239990
TUF= 15064.333984
cp= 0.000000
cs= 0.000000
```

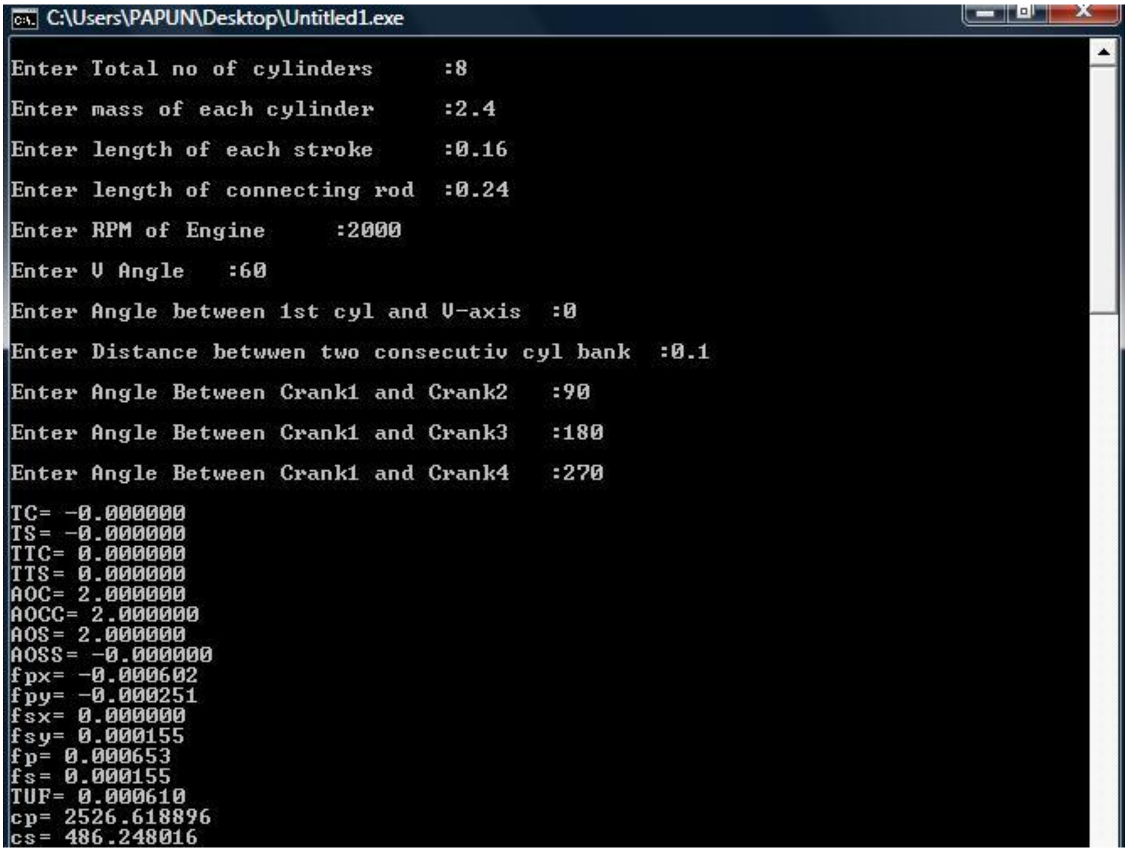
FOR V-4 ENGINE

```
Select C:\Users\PAPUN\Desktop\Untitled1.exe

Enter Total no of cylinders     :4
Enter mass of each cylinder     :2.4
Enter length of each stroke     :0.16
Enter length of connecting rod  :0.24
Enter RPM of Engine      :2000
Enter V Angle    :60
Enter Angle between 1st cyl and V-axis   :0
Enter Distance betwen two consecutiv cyl bank   :0.1
Enter Angle Between Crank1 and Crank2    :180
TC= 0.000000
TS= -0.000000
TTC= 2.000000
TTS= 0.000000
AOC= 1.000000
AOCC= 0.000000
AOS= 0.000000
AOSS= -0.000000
fpx= 0.000000
fpy= -0.000368
fsx= 4862.479980
fsy= 0.000425
fp= 0.000368
fs= 4862.479980
TUF= 4862.479980
cp= 1263.309448
cs= 0.000000
```

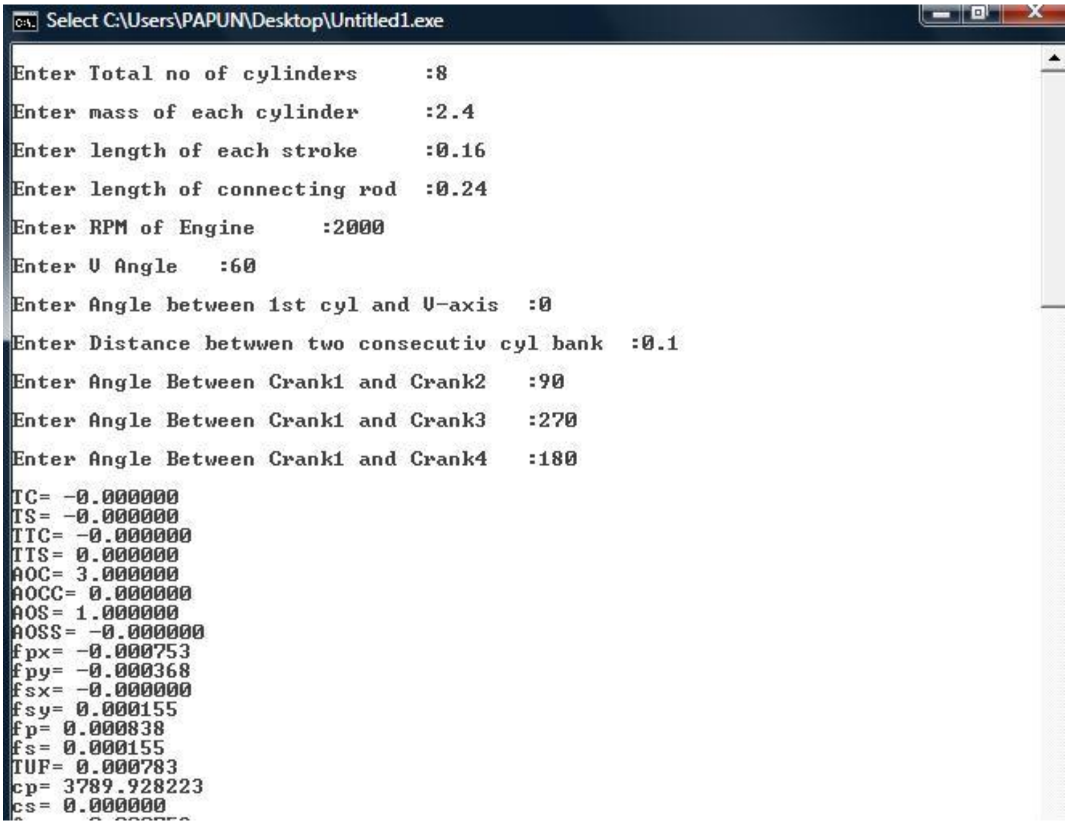
FOR V-6 ENGINE

```
Select C:\Users\PAPUN\Desktop\Untitled1.exe

Enter Total no of cylinders     :6
Enter mass of each cylinder     :2.4
Enter length of each stroke     :0.16
Enter length of connecting rod  :0.24
Enter RPM of Engine      :2000
Enter V Angle    :60
Enter Angle between 1st cyl and V-axis   :0
Enter Distance betwen two consecutiv cyl bank   :0.1
Enter Angle Between Crank1 and Crank2    :120
Enter Angle Between Crank1 and Crank3    :240
TC= 0.000000
TS= -0.000000
TTC= -0.000000
TTS= -0.000000
AOC= 1.500000
AOCC= 1.500000
AOS= 0.866025
AOSS= -0.866025
fpx= 0.000522
fpy= -0.000311
fsx= -0.000201
fsy= -0.000391
fp= 0.000608
fs= 0.000439
TUF= 0.000771
cp= 1894.963989
cs= 364.686066
```

FOR V-8 ENGINE

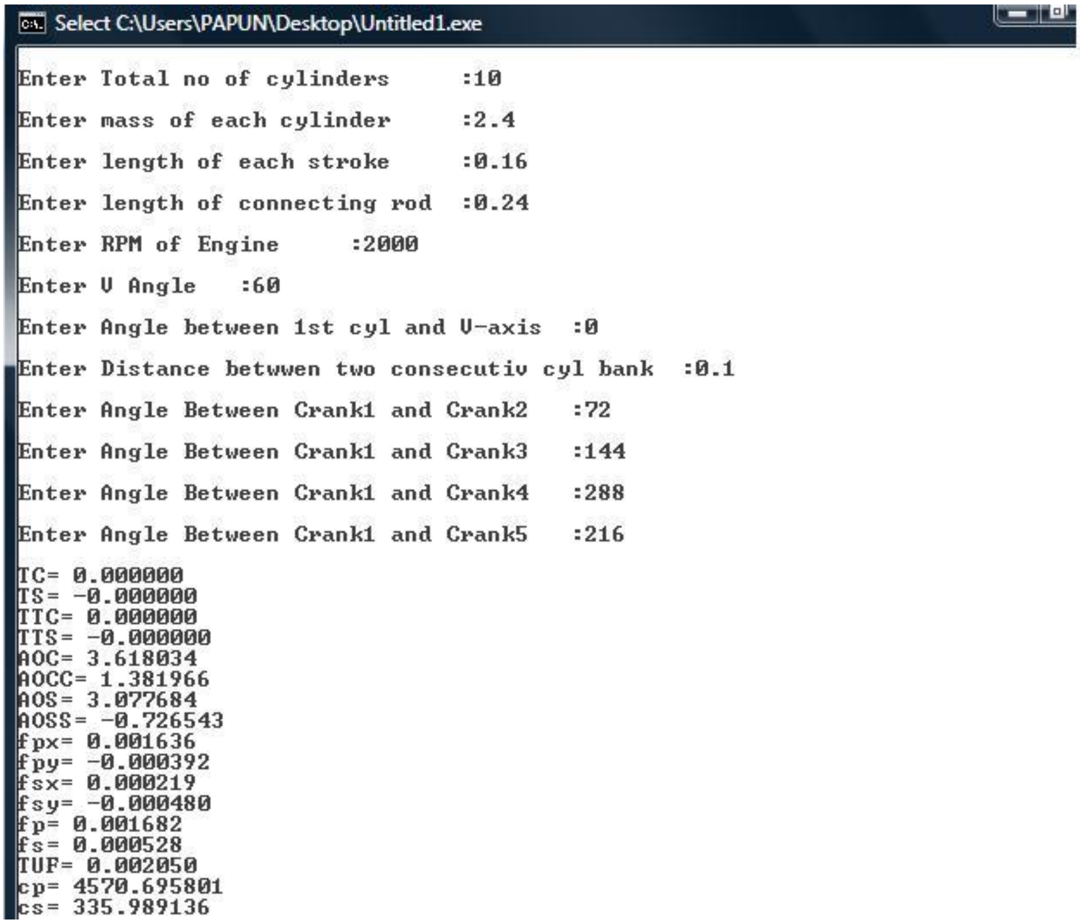


```
C:\Users\PAPUN\Desktop\Untitled1.exe
Enter Total no of cylinders     :8
Enter mass of each cylinder     :2.4
Enter length of each stroke     :0.16
Enter length of connecting rod  :0.24
Enter RPM of Engine     :2000
Enter V Angle   :60
Enter Angle between 1st cyl and V-axis  :0
Enter Distance betwwen two consecutiv cyl bank  :0.1
Enter Angle Between Crank1 and Crank2   :90
Enter Angle Between Crank1 and Crank3   :180
Enter Angle Between Crank1 and Crank4   :270
TC= -0.000000
TS= -0.000000
TTC= 0.000000
TTS= 0.000000
AOC= 2.000000
AOCC= 2.000000
AOS= 2.000000
AOSS= -0.000000
fpx= -0.000602
fpy= -0.000251
fsx= 0.000000
fsy= 0.000155
fp= 0.000653
fs= 0.000155
TUF= 0.000610
cp= 2526.618896
cs= 486.248016
```



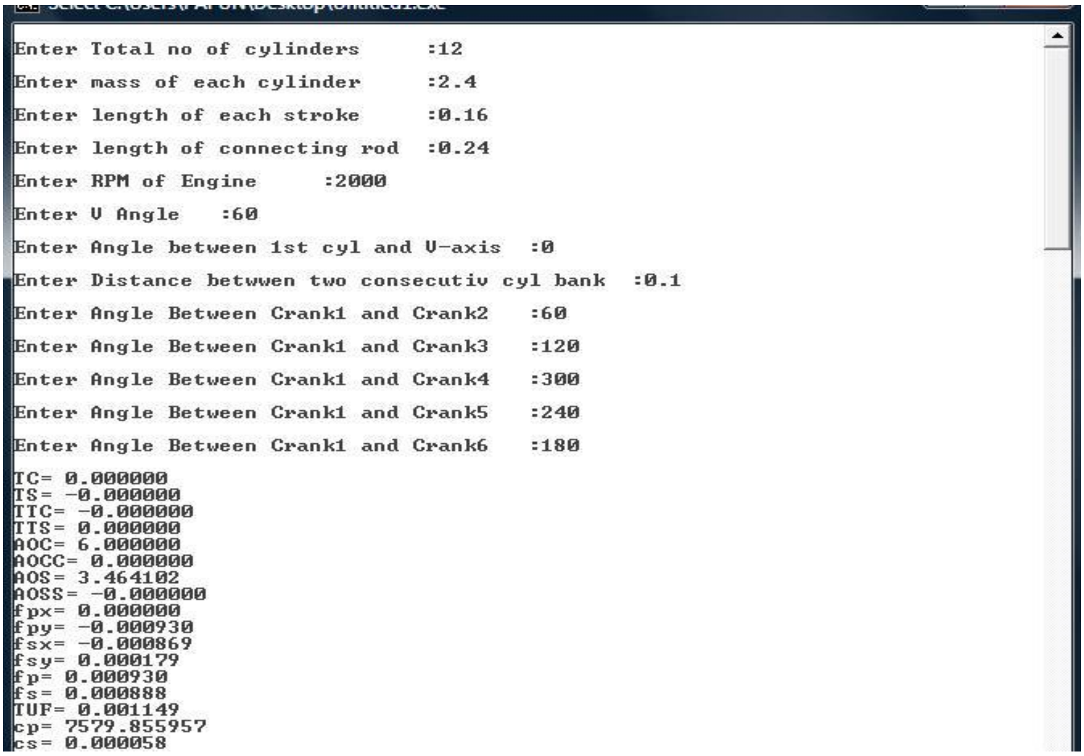
```
Select C:\Users\PAPUN\Desktop\Untitled1.exe
Enter Total no of cylinders     :8
Enter mass of each cylinder     :2.4
Enter length of each stroke     :0.16
Enter length of connecting rod  :0.24
Enter RPM of Engine     :2000
Enter V Angle   :60
Enter Angle between 1st cyl and V-axis  :0
Enter Distance betwwen two consecutiv cyl bank  :0.1
Enter Angle Between Crank1 and Crank2   :90
Enter Angle Between Crank1 and Crank3   :270
Enter Angle Between Crank1 and Crank4   :180
TC= -0.000000
TS= -0.000000
TTC= -0.000000
TTS= 0.000000
AOC= 3.000000
AOCC= 0.000000
AOS= 1.000000
AOSS= -0.000000
fpx= -0.000753
fpy= -0.000368
fsx= -0.000000
fsy= 0.000155
fp= 0.000838
fs= 0.000155
TUF= 0.000783
cp= 3789.928223
cs= 0.000000
```

FOR V-10 ENGINE



```
Select C:\Users\PAPUN\Desktop\Untitled1.exe

Enter Total no of cylinders      :10
Enter mass of each cylinder      :2.4
Enter length of each stroke      :0.16
Enter length of connecting rod   :0.24
Enter RPM of Engine      :2000
Enter V Angle    :60
Enter Angle between 1st cyl and V-axis   :0
Enter Distance betwwen two consecutiv cyl bank   :0.1
Enter Angle Between Crank1 and Crank2    :72
Enter Angle Between Crank1 and Crank3    :144
Enter Angle Between Crank1 and Crank4    :288
Enter Angle Between Crank1 and Crank5    :216
TC= 0.000000
TS= -0.000000
TTC= 0.000000
TTS= -0.000000
AOC= 3.618034
AOCC= 1.381966
AOS= 3.077684
AOSS= -0.726543
fpx= 0.001636
fpy= -0.000392
fsx= 0.000219
fsy= -0.000480
fp= 0.001682
fs= 0.000528
TUF= 0.002050
cp= 4570.695801
cs= 335.989136
```

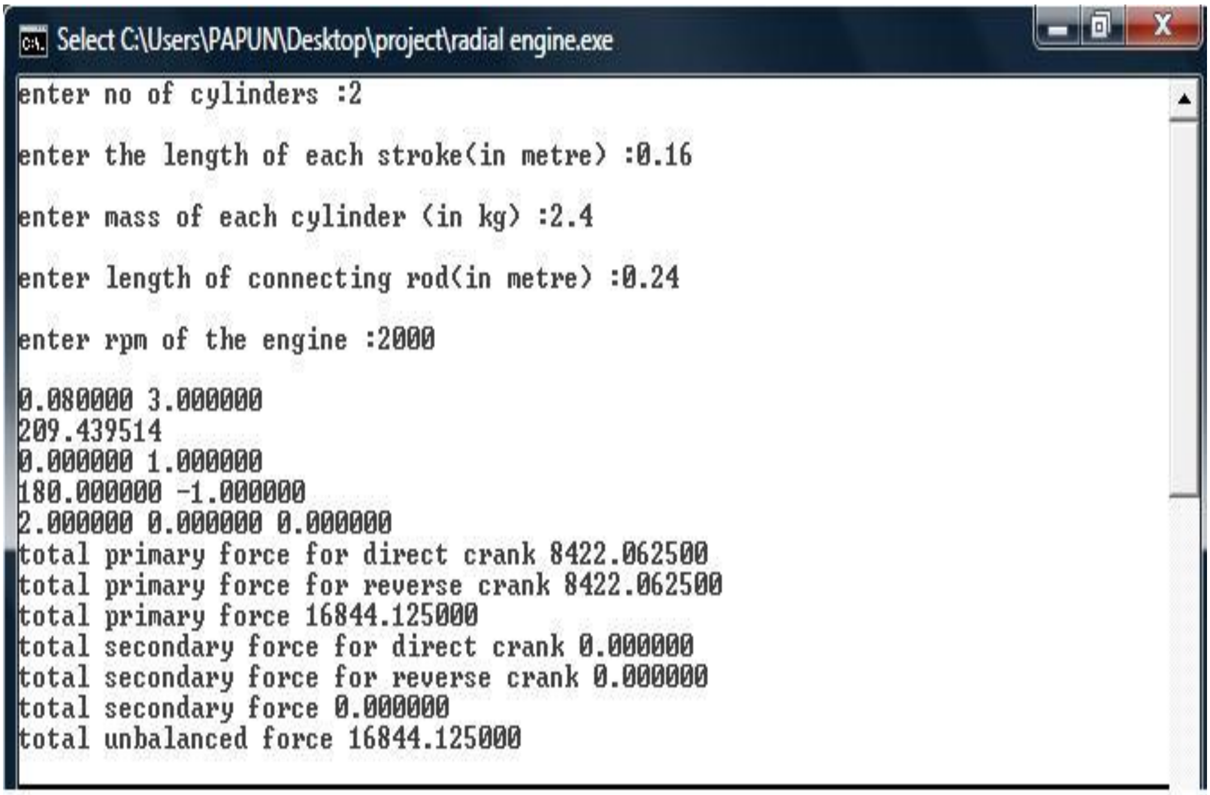
FOR V-12 ENGINE



```
Enter Total no of cylinders      :12
Enter mass of each cylinder      :2.4
Enter length of each stroke      :0.16
Enter length of connecting rod   :0.24
Enter RPM of Engine      :2000
Enter V Angle    :60
Enter Angle between 1st cyl and V-axis   :0
Enter Distance betwwen two consecutiv cyl bank   :0.1
Enter Angle Between Crank1 and Crank2    :60
Enter Angle Between Crank1 and Crank3    :120
Enter Angle Between Crank1 and Crank4    :300
Enter Angle Between Crank1 and Crank5    :240
Enter Angle Between Crank1 and Crank6    :180
TC= 0.000000
TS= -0.000000
TTC= -0.000000
TTS= 0.000000
AOC= 6.000000
AOCC= 0.000000
AOS= 3.464102
AOSS= -0.000000
fpx= 0.000000
fpy= -0.000930
fsx= -0.000869
fsy= 0.000179
fp= 0.000930
fs= 0.000888
TUF= 0.001149
cp= 7579.855957
cs= 0.000058
```

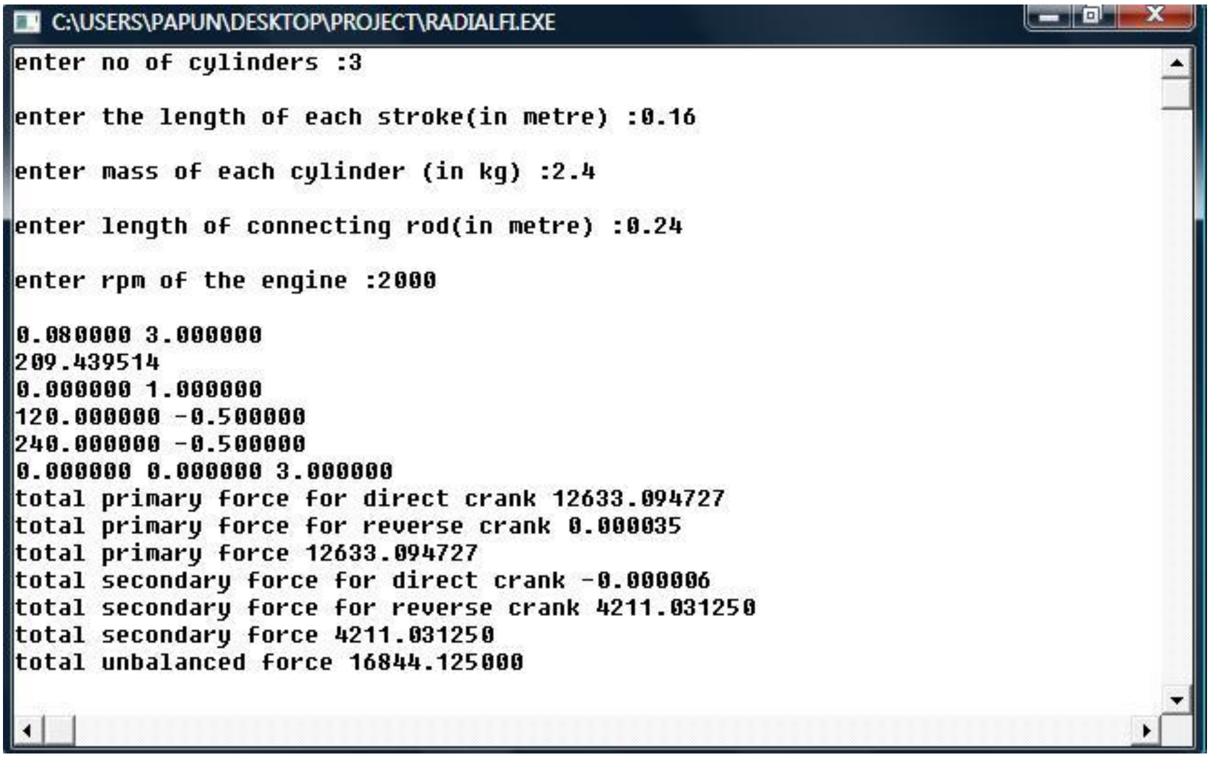
Values considered for radial engine:
Mass of each cylinder : 2,4 kg
RPM of the engine 2000
Length of each stroke 0.16m
Length of connecting rod 0.24m
Unbalance forces are calculated for varying no. Of cylinders

For R-2 engine

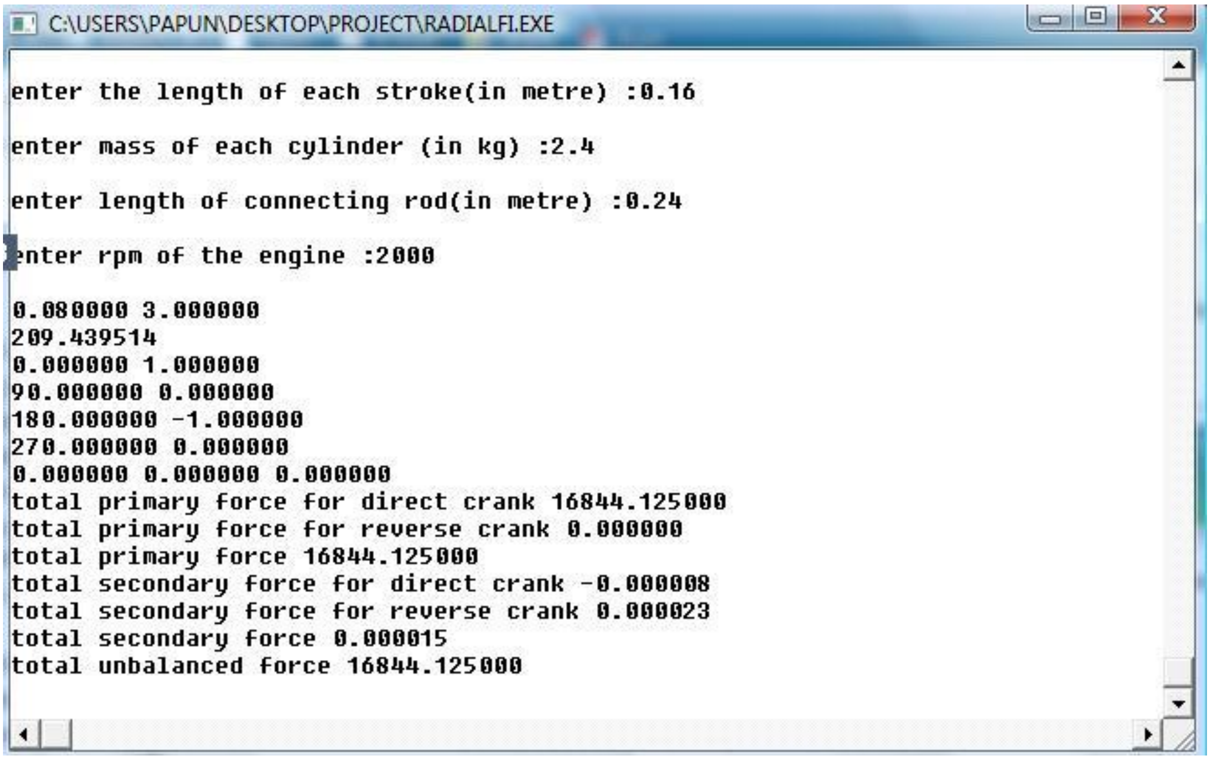



```
enter no of cylinders :2

enter the length of each stroke(in metre) :0.16

enter mass of each cylinder (in kg) :2.4

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
180.000000 -1.000000
2.000000 0.000000 0.000000
total primary force for direct crank 8422.062500
total primary force for reverse crank 8422.062500
total primary force 16844.125000
total secondary force for direct crank 0.000000
total secondary force for reverse crank 0.000000
total secondary force 0.000000
total unbalanced force 16844.125000
```

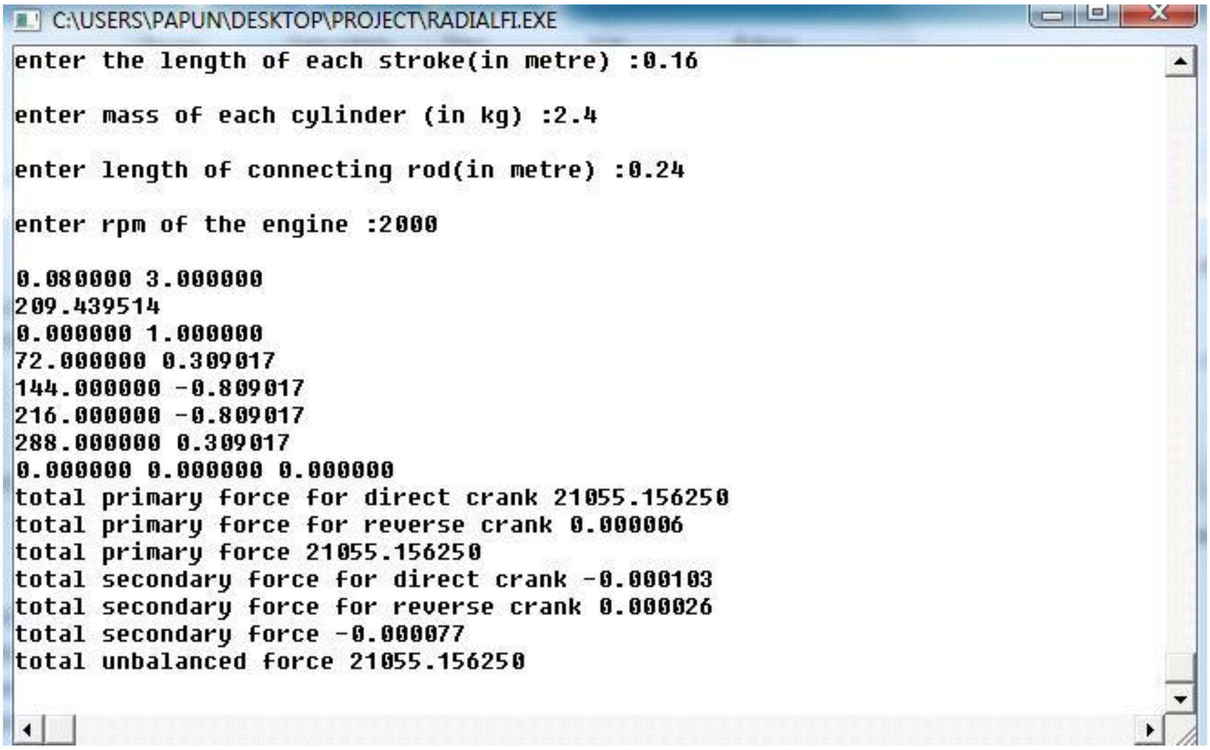
For R-3 Engine



For R-4 Engine



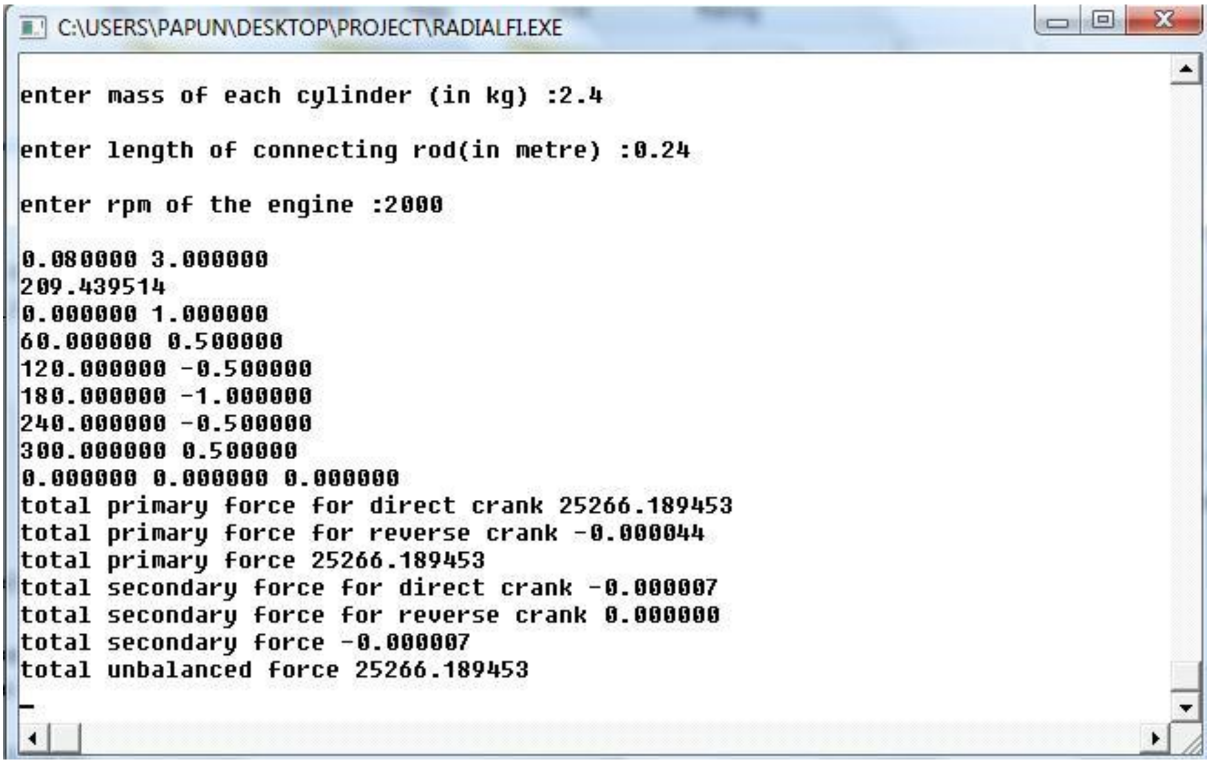
For R-5 Engine



C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE

```
enter the length of each stroke(in metre) :0.16

enter mass of each cylinder (in kg) :2.4

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
72.000000 0.309017
144.000000 -0.809017
216.000000 -0.809017
288.000000 0.309017
0.000000 0.000000 0.000000
total primary force for direct crank 21055.156250
total primary force for reverse crank 0.000006
total primary force 21055.156250
total secondary force for direct crank -0.000103
total secondary force for reverse crank 0.000026
total secondary force -0.000077
total unbalanced force 21055.156250
```

For R-6 engine



C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE

```
enter mass of each cylinder (in kg) :2.4

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
60.000000 0.500000
120.000000 -0.500000
180.000000 -1.000000
240.000000 -0.500000
300.000000 0.500000
0.000000 0.000000 0.000000
total primary force for direct crank 25266.189453
total primary force for reverse crank -0.000044
total primary force 25266.189453
total secondary force for direct crank -0.000007
total secondary force for reverse crank 0.000000
total secondary force -0.000007
total unbalanced force 25266.189453
_
```

For R-7 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE
enter mass of each cylinder (in kg) :2.4

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
51.428570 0.623490
102.857140 -0.222521
154.285706 -0.900969
205.714279 -0.900969
257.142853 -0.222521
308.571411 0.623490
-0.000001 0.000000 -0.000001
total primary force for direct crank 29477.220703
total primary force for reverse crank -0.002493
total primary force 29477.218750
total secondary force for direct crank -0.000167
total secondary force for reverse crank -0.001346
total secondary force -0.001513
total unbalanced force 29477.216797
_
```

For R-8 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
45.000000 0.707107
90.000000 0.000000
135.000000 -0.707107
180.000000 -1.000000
225.000000 -0.707107
270.000000 0.000000
315.000000 0.707107
0.000000 0.000000 0.000000
total primary force for direct crank 33688.250000
total primary force for reverse crank -0.000053
total primary force 33688.250000
total secondary force for direct crank 0.000011
total secondary force for reverse crank -0.000036
total secondary force -0.000025
total unbalanced force 33688.250000
_
```

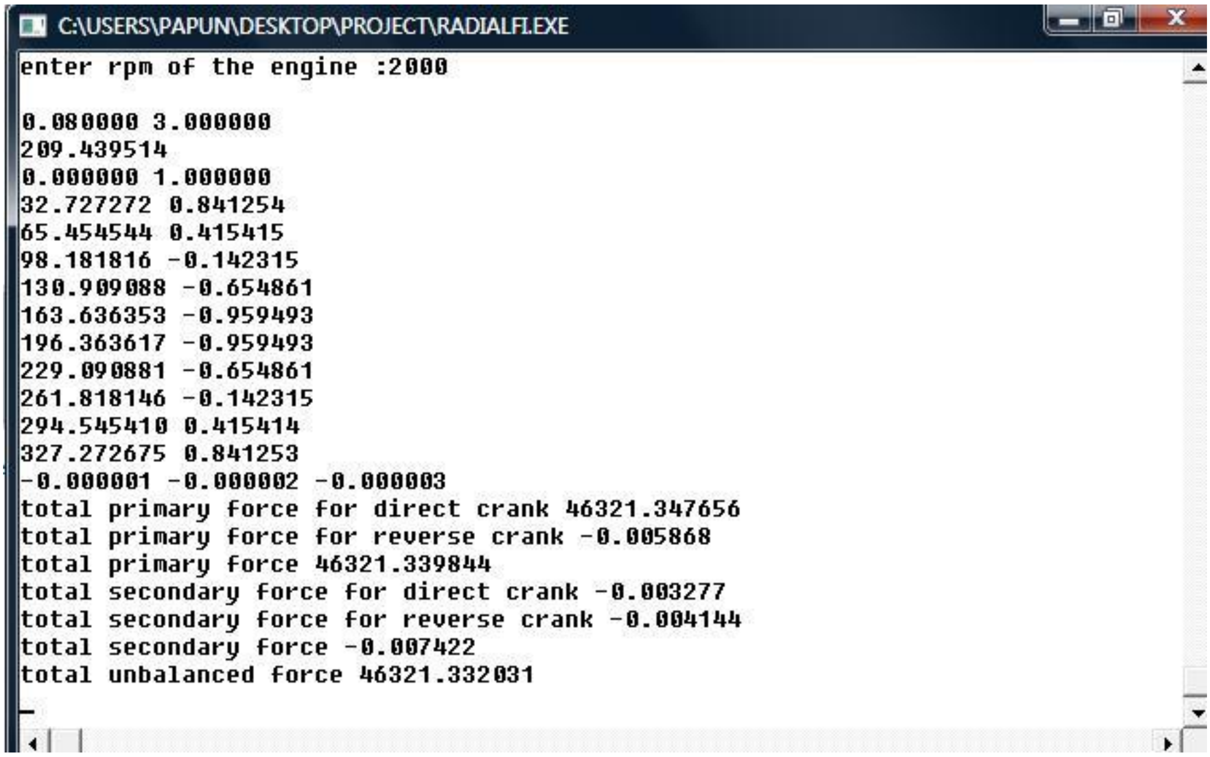
For R-9 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE
enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
40.000000 0.766044
80.000000 0.173648
120.000000 -0.500000
160.000000 -0.939693
200.000000 -0.939693
240.000000 -0.500000
280.000000 0.173648
320.000000 0.766044
0.000000 0.000000 0.000000
total primary force for direct crank 37899.281250
total primary force for reverse crank 0.000131
total primary force 37899.281250
total secondary force for direct crank 0.000169
total secondary force for reverse crank -0.000023
total secondary force 0.000146
total unbalanced force 37899.281250
```

For R-10 engine

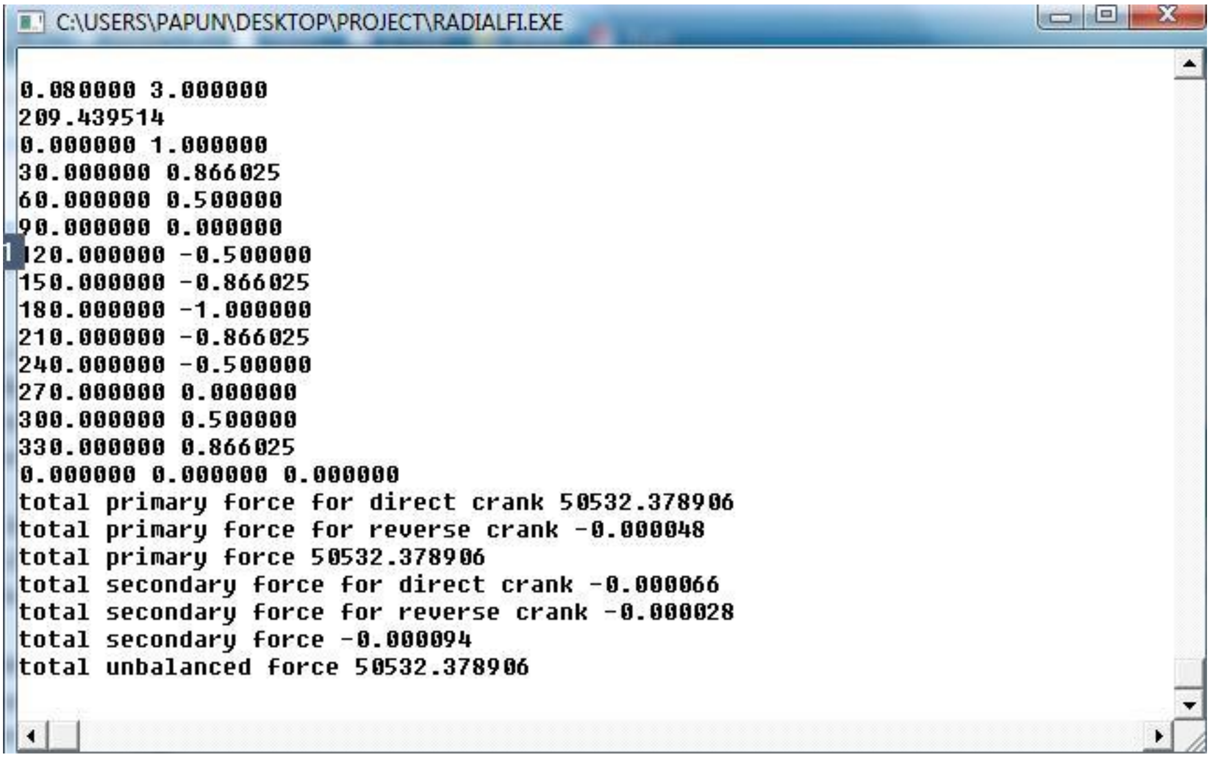
```
C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE

enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
36.000000 0.809017
72.000000 0.309017
108.000000 -0.309017
144.000000 -0.809017
180.000000 -1.000000
216.000000 -0.809017
252.000000 -0.309017
288.000000 0.309017
324.000000 0.809017
0.000000 0.000000 0.000000
total primary force for direct crank 42110.312500
total primary force for reverse crank -0.000337
total primary force 42110.312500
total secondary force for direct crank -0.000017
total secondary force for reverse crank 0.000027
total secondary force 0.000011
total unbalanced force 42110.312500
_
```

For R-11 engine



```
C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE
enter rpm of the engine :2000

0.080000 3.000000
209.439514
0.000000 1.000000
32.727272 0.841254
65.454544 0.415415
98.181816 -0.142315
130.909088 -0.654861
163.636353 -0.959493
196.363617 -0.959493
229.090881 -0.654861
261.818146 -0.142315
294.545410 0.415414
327.272675 0.841253
-0.000001 -0.000002 -0.000003
total primary force for direct crank 46321.347656
total primary force for reverse crank -0.005868
total primary force 46321.339844
total secondary force for direct crank -0.003277
total secondary force for reverse crank -0.004144
total secondary force -0.007422
total unbalanced force 46321.332031
```

For R-12 engine



```
C:\USERS\PAPUN\DESKTOP\PROJECT\RADIALFI.EXE

0.080000 3.000000
209.439514
0.000000 1.000000
30.000000 0.866025
60.000000 0.500000
90.000000 0.000000
120.000000 -0.500000
150.000000 -0.866025
180.000000 -1.000000
210.000000 -0.866025
240.000000 -0.500000
270.000000 0.000000
300.000000 0.500000
330.000000 0.866025
0.000000 0.000000 0.000000
total primary force for direct crank 50532.378906
total primary force for reverse crank -0.000048
total primary force 50532.378906
total secondary force for direct crank -0.000066
total secondary force for reverse crank -0.000028
total secondary force -0.000094
total unbalanced force 50532.378906
```

Values taken for multiple rows combined radial engine

Mass of each cylinder 2.4 kg

Length of each stroke 0.16m

Length of connecting rod 0.24m

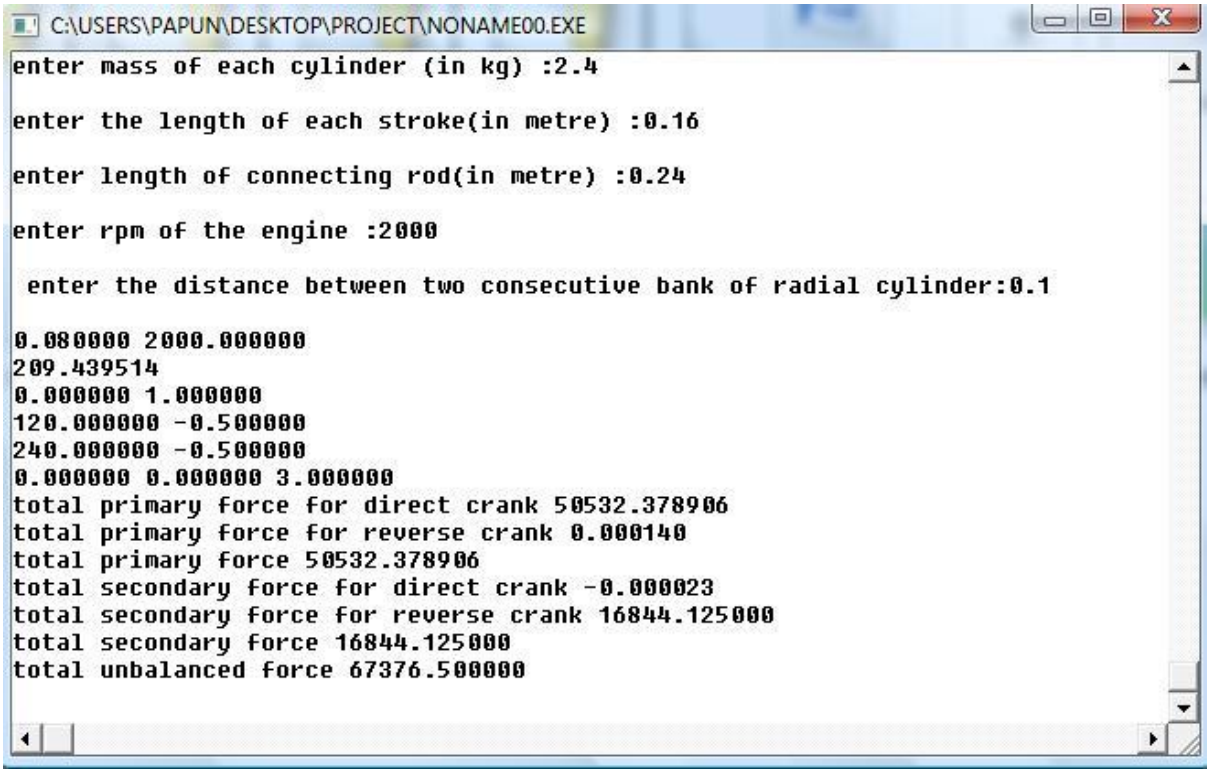
Speed of the engine 2000 RPM
Distance between each bank 0.1m
2- Row R-3 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE
enter mass of each cylinder (in kg) :2.4

enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
120.000000 -0.500000
240.000000 -0.500000
0.000000 0.000000 3.000000
total primary force for direct crank 25266.189453
total primary force for reverse crank 0.000070
total primary force 25266.189453
total secondary force for direct crank -0.000012
total secondary force for reverse crank 8422.062500
total secondary force 8422.062500
total unbalanced force 33688.250000
_
```

3 Rows R-3 Engine

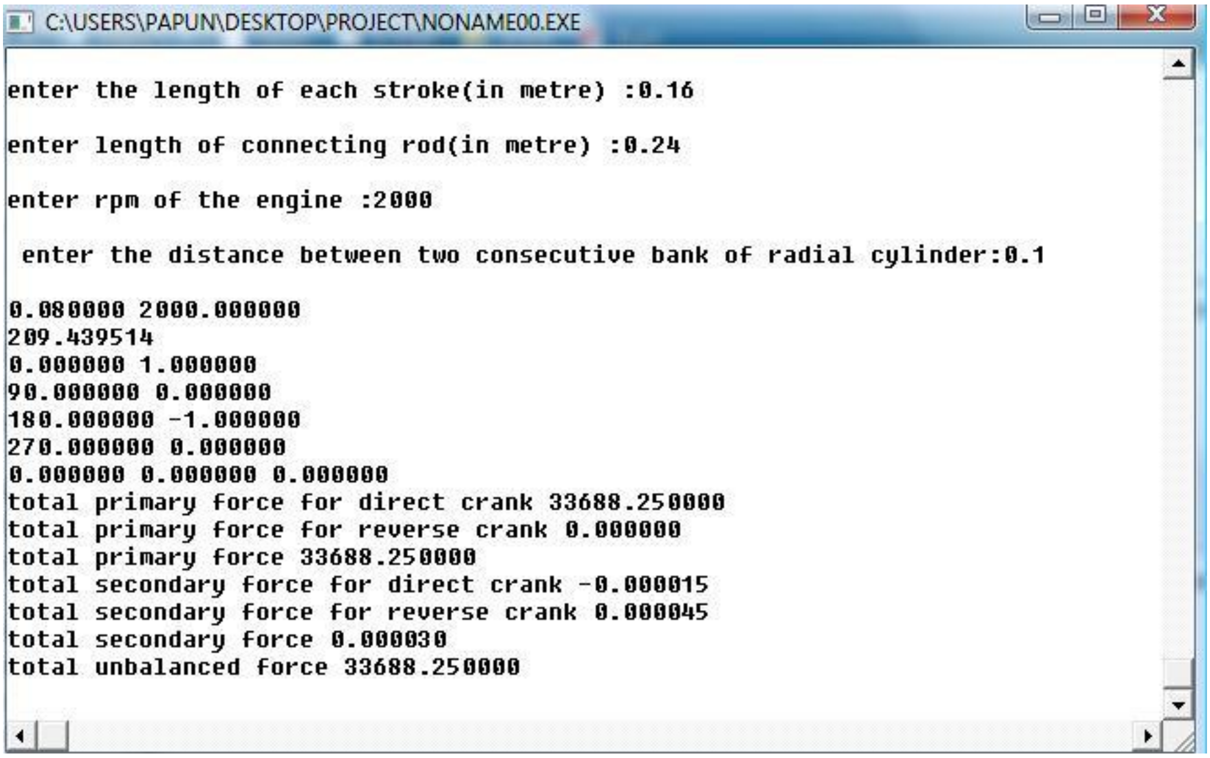
```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE
enter mass of each cylinder (in kg) :2.4

enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
120.000000 -0.500000
240.000000 -0.500000
0.000000 0.000000 3.000000
total primary force for direct crank 37899.281250
total primary force for reverse crank 0.000105
total primary force 37899.281250
total secondary force for direct crank -0.000017
total secondary force for reverse crank 12633.094727
total secondary force 12633.094727
total unbalanced force 50532.375000
```

4 Rows R-3 engine



```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE
enter mass of each cylinder (in kg) :2.4

enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
120.000000 -0.500000
240.000000 -0.500000
0.000000 0.000000 3.000000
total primary force for direct crank 50532.378906
total primary force for reverse crank 0.000140
total primary force 50532.378906
total secondary force for direct crank -0.000023
total secondary force for reverse crank 16844.125000
total secondary force 16844.125000
total unbalanced force 67376.500000
```

2 Rows R-4 engine



```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE

enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
90.000000 0.000000
180.000000 -1.000000
270.000000 0.000000
0.000000 0.000000 0.000000
total primary force for direct crank 33688.250000
total primary force for reverse crank 0.000000
total primary force 33688.250000
total secondary force for direct crank -0.000015
total secondary force for reverse crank 0.000045
total secondary force 0.000030
total unbalanced force 33688.250000
```

3 Rows R-4 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE

enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
90.000000 0.000000
180.000000 -1.000000
270.000000 0.000000
0.000000 0.000000 0.000000
total primary force for direct crank 50532.378906
total primary force for reverse crank 0.000000
total primary force 50532.378906
total secondary force for direct crank -0.000023
total secondary force for reverse crank 0.000068
total secondary force 0.000045
total unbalanced force 50532.378906
_
```

4 Rows R-4 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE

enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
90.000000 0.000000
180.000000 -1.000000
270.000000 0.000000
0.000000 0.000000 0.000000
total primary force for direct crank 67376.500000
total primary force for reverse crank 0.000000
total primary force 67376.500000
total secondary force for direct crank -0.000030
total secondary force for reverse crank 0.000091
total secondary force 0.000060
total unbalanced force 67376.500000
```

2 Rows R-5 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE
enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
72.000000 0.309017
144.000000 -0.809017
216.000000 -0.809017
288.000000 0.309017
0.000000 0.000000 0.000000
total primary force for direct crank 42110.312500
total primary force for reverse crank 0.000012
total primary force 42110.312500
total secondary force for direct crank -0.000206
total secondary force for reverse crank 0.000051
total secondary force -0.000154
total unbalanced force 42110.312500
_
```

3 Rows R-5 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE
enter the length of each stroke(in metre) :0.16

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
72.000000 0.309017
144.000000 -0.809017
216.000000 -0.809017
288.000000 0.309017
0.000000 0.000000 0.000000
total primary force for direct crank 63165.472656
total primary force for reverse crank 0.000018
total primary force 63165.472656
total secondary force for direct crank -0.000309
total secondary force for reverse crank 0.000077
total secondary force -0.000231
total unbalanced force 63165.472656
_
```

2 Rows R-6 engine

```
C:\USERS\PAPUN\DESKTOP\PROJECT\NONAME00.EXE

enter length of connecting rod(in metre) :0.24

enter rpm of the engine :2000

 enter the distance between two consecutive bank of radial cylinder:0.1

0.080000 2000.000000
209.439514
0.000000 1.000000
60.000000 0.500000
120.000000 -0.500000
180.000000 -1.000000
240.000000 -0.500000
300.000000 0.500000
0.000000 0.000000 0.000000
total primary force for direct crank 50532.378906
total primary force for reverse crank -0.000087
total primary force 50532.378906
total secondary force for direct crank -0.000015
total secondary force for reverse crank 0.000000
total secondary force -0.000015
total unbalanced force 50532.378906
```

Comparisons of unbalanced forces and couple for different configuration

No. Of cylinders = 2

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple(KN-m)	Unbalanced secondary couple (KN-m)
V-2	12.63	2.431	15.064	0	0
R-2	16.844	0	16.84	0	0

No. Of cylinders = 4

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple(KN-m)	Unbalanced secondary couple (KN-m)
V-4	0	4.862	4.862	1.263	0
R-4	16.844	0	16.84	0	0

No. Of cylinders = 6

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple along central axis(KN-m)	Unbalanced secondary couple along central axis (KN-m)
V-6	0	0	0	1.894	0.364
R-6	25.266	0	25.266	0	0
2row R-3	25.266	0	25.266	0	0

No. Of cylinders = 8

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple(KN-m)	Unbalanced secondary couple (KN-m)
V-8	0	0	0	3.789	0
R-8	33.688	0	33.688	0	0
2 row R-4	33.688	0	33.688	0	0

No. Of cylinders = 9

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple(KN-m)	Unbalanced secondary couple (KN-m)
R-9	37.899	0	37.899	0	0
3row R-3	37.899	12.6	50.5	0	0

No. Of cylinders = 10

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple(KN-m)	Unbalanced secondary couple (KN-m)
V-10	0	0	0	4.57	0.335
R-10	42.11	0	42.11	0	0
2 row R-5	42.11	0	42.11	0	0

No. Of cylinders = 12

Types of configuration	Unbalanced Primary force (KN)	Unbalanced Secondary force (KN)	Unbalanced Force(KN)	Unbalanced primary couple(KN-m)	Unbalanced secondary couple (KN-m)
V-12	0	0	0	4.57	0.335
R-12	42.11	0	42.11	0	0
2 row R-6	50.5	0	50.5	0	0
3 rows R-4	50.5	0	50.5	0	0
4 rows R-3	50.5	16.8	67.3	0	0

The above data shows primary and secondary unbalanced forces are 0 for v configured engine having engines more than four. Where as in case of radial engine secondary unbalanced force and couple are 0.when R-3 engines are combined together the total unbalance force is more than the counterpart radial engine having total no. Of cylinders are same.

CONCLUSION

on comparing radial engines and multiple row radial engines it is found that the multiple row radial engines are better as they are easy to manufacture. Higher no. Of cylinders can be achieved. It is highly applicable where higher power is required. it is generally used in aircraft engine.

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